MARQUIS

A Discussion of Train Resistance with Special Reference to the Effect of Variations in Loading on the Resistance of Freight Trains

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# A DISCUSSION OF TRAIN RESISTANCE WITH SPECIAL REFERENCE TO THE EFFECT OF VARIATIONS IN LOADING ON THE RESISTANCE OF FREIGHT TRAINS

BY

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THESIS

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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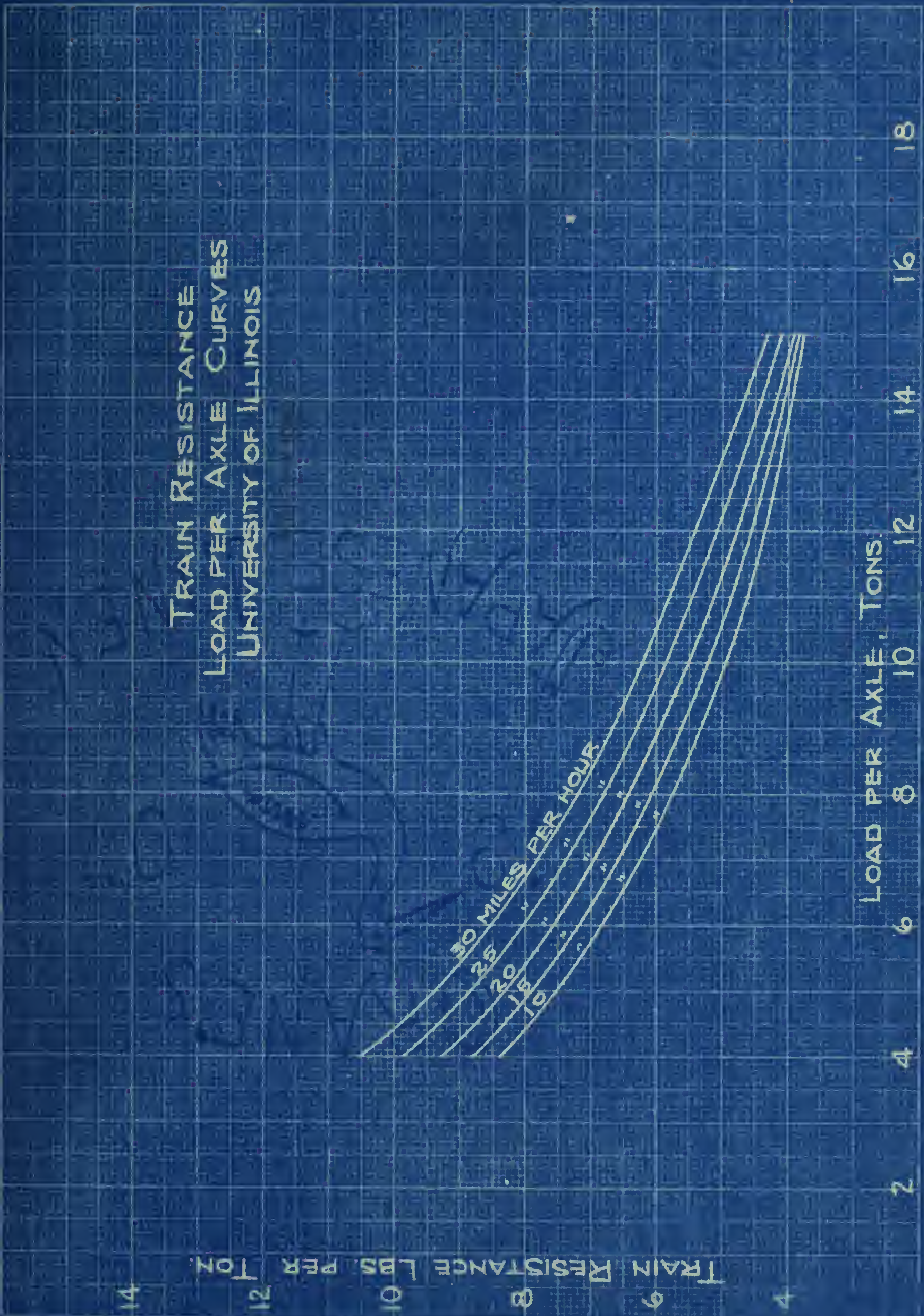
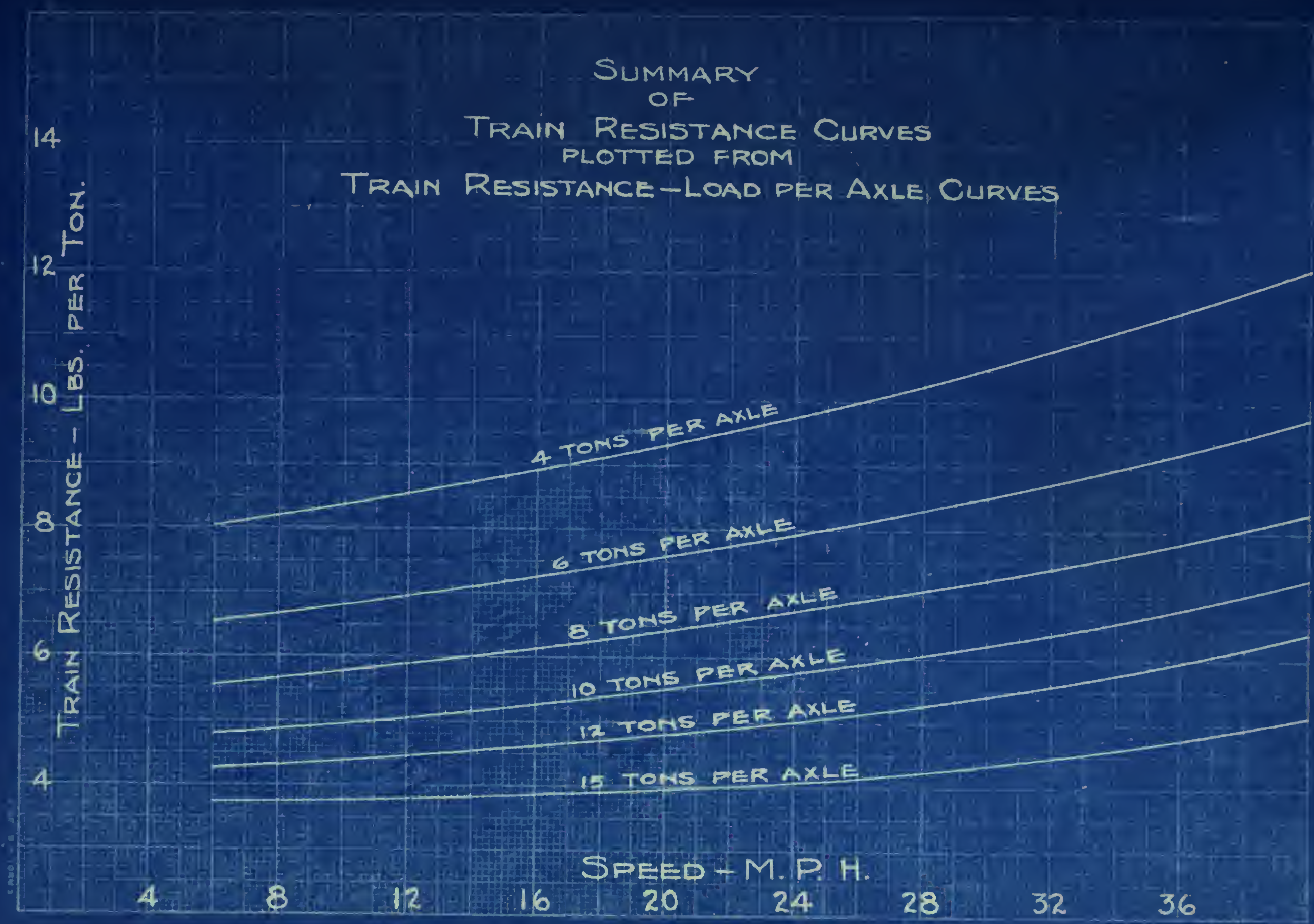
A DISCUSSION OF TRAIN RESISTANCE, WITH SPECIAL REFERENCE TO THE EFFECT OF VARIATIONS IN LOADING ON THE RESISTANCE OF FREIGHT TRAINS.

It is proposed, in the following pages, to present the results of a series of experiments which were made to determine the effect of variations in loading, or as it may be expressed, variations in the weight carried per axle, upon the resistance of freight trains. The final results of these experiments expressed in the form of curves, will be found on pages 2 and 3.

There have been many attempts, in connection with steam railway practice, to determine a relation between the weight hauled and the power required, a knowledge of this relation being of prime importance in connection with the vital problem of tonnage rating of locomotives. A constantly increasing number of investigators have endeavored to determine experimentally just what this relation is, most of these men having derived, from the results of their experiments empirical train resistance formulae. Much of this work was undoubtedly done with the greatest of care, every precaution being taken to insure accuracy in results. However, even if consideration is limited to those experiments in which the greatest care was taken, the results, as expressed by the train resistance formulae, vary within rather wide limits. It has been recognized for a long time that variations in loading, i.e., variations in the weight carried per axle, have



TRAIN RESISTANCE
LOAD PER AXLE CURVES
UNIVERSITY OF ILLINOIS
30 MILES PER HOUR
25 " " "
20 " " "
15 " " "
10 " " "
LOAD PER AXLE, TONS
TRAIN RESISTANCE LBS. PER TON
2
4
6
8
10
12
14
16
18
4
6
8
10
12
14


SUMMARY
OF
TRAIN RESISTANCE CURVES
PLOTTED FROM
TRAIN RESISTANCE—LOAD PER AXLE CURVES
14
12
10
8
6
4
TRAIN RESISTANCE - LBS. PER TON.
4 TONS PER AXLE
6 TONS PER AXLE
8 TONS PER AXLE
10 TONS PER AXLE
12 TONS PER AXLE
15 TONS PER AXLE
SPEED - M. P. H.
4
8
12
16
20
24
28
32
36

a marked influence on train resistance. However, there seems at the present time, to be very little definite information about this.Certainly, very few of the above mentioned investigators, if any, have made any attempt to take care of this factor in the formulae which they have derived. This fact undoubtedly explains, to a large extent, the lack of uniformity which appears in the results as expressed in the different formulae.

For the reasons stated above, it was determined to make the series of tests which are here reported. The following pages contain a report of eighteen of these tests, including a description of the apparatus and methods used in making them, together with an explanation of the methods of calculation and a display of the results obtained.

## "TRAIN RESISTANCE" DEFINED.

By the term "Train Resistance" as here used, is meant that resistance which opposes the motion of a train when running on a straight level track. in still air, at a uniform speed, not including the resistance of the locomotive. It may be considered as being made up of the following resistances:-

1. RESISTANCE DUE TO JOURNAL FRICTION. - This is subject to the laws of friction in journals.
2. ROLLING RESISTANCE. - This is the resistance of the wheel in rolling on the rail. It is due to imperfect elasticity of materials and to deviation from the true surface, deflections of rail and rail joints, etc.
3. RESISTANCE DUE TO FLANGE FRICTION.
4. OSCILLATORY RESISTANCES. - These are made up of movements of the car body and trucks, causing shocks, the production of which absorbs energy.
5. AIR RESISTANCES. - These are made up of impact and friction in still air, and of motions communicated to the air.

The foregoing are always acting to retard the train when running under the conditions mentioned above. In addition to these, there may be, under certain circumstances, the

following resistances, which are not inherent in the train itself, and which may be called auxiliary or "accidental" resistances. They may be in operation all together, or each separately may act in conjunction with the true train resistance as noted above. In amount they frequently exceed the former, and in the operation of freight trains they are generally the more important.

6. RESISTANCE DUE TO GRADE.
7. RESISTANCE DUE TO ACCELERATION.
8. RESISTANCE DUE TO CURVES.
9. WIND RESISTANCE.

The sum of the true train resistance (items 1 to 5 above) and the "accidental" resistances (items 6 to 9) may be termed the "gross" train resistance.

## METHOD OF CONDUCTING TESTS.

All tests were run on the Illinois Central Railroad, either between Champaign and Gilman, a distance of 46.7 miles, or between Champaign and Mattoon, a distance of 44.5 miles. Over this section the track is made up of 85 pound rails, laid in rock ballast. There are no heavy grades, the heaviest being only a trifle over 0.5 per cent, and there are very few curves. No results were calculated from data obtained on curves.

A profile of this section of track was made especially for use in connection with these tests, elevations being taken at intervals of 300 feet. In every test, the trains were weighed on track scales before starting. All runs were made with trains in extra freight service, and it was attempted to have trains made up so as to give the desired range of loading, this being accomplished rather satisfactorily.

Test Car No. 17, a description of which is given in Appendix C, was used in all tests. In it, as explained in Appendix C, graphical records were obtained of the following data:-

Curve of draw-bar pull.

Speed curve.

Record of time.

Record of position of mile posts, stations, etc.

Record of air brake applications.

Record of wind direction.

Record of wind velocity.

The following data also were recorded for each test:-

Gross weight and stencilled light weight of each car.

Number, initial, and kind of car, for each car.

Total number of cars in train, and number of loads and empties.

Length of train (obtained by counting rail lengths).

In every test the train was watched carefully for anything which might influence train resistance, such as sticking brakes, hot boxes, etc., notes of all such things being recorded.

## RESULTS OBTAINED.

A summary of train resistance curves for all tests, plotted with reference to speed, and a table containing the most important data about each text, will be found on pages 12 and 13 . The data for each one of these curves ~~was~~ were obtained by determining for each test, the true train resistance at a number of different points, and over a number of different sections, these points and sections being selected so as to cover as wide a speed range as possible. These true train resistances were then plotted on a speed base, and a curve located with reference to them. In Appendix B, a curve for each test is given, on which the points from which the curve was located, are shown. Complete data concerning each test will also be found in Appendix B. Complete information con-

cerning the methods of calculation employed, will be found in Appendix A.

A glance at the "Summary of Train Resistance Curves" on page 12 , shows that there was a great variation in train resistance for the different tests. A large part of this variation must be ascribed to variations in load per axle, since it was attempted to hold all conditions, except load per axle, as nearly constant as possible for all tests. The curves previously referred to, on page 2, and also curves on pages 109, 110, and 111 in Appendix B, show this variation in resistance due to variations in load per axle. The data for each one of these curves ~~was~~ were obtained by taking the train resistance at a certain speed from each one of the curves given on page 12 and plotting these resistances on a load per axle base, the curve being located with reference to the points thus obtained.

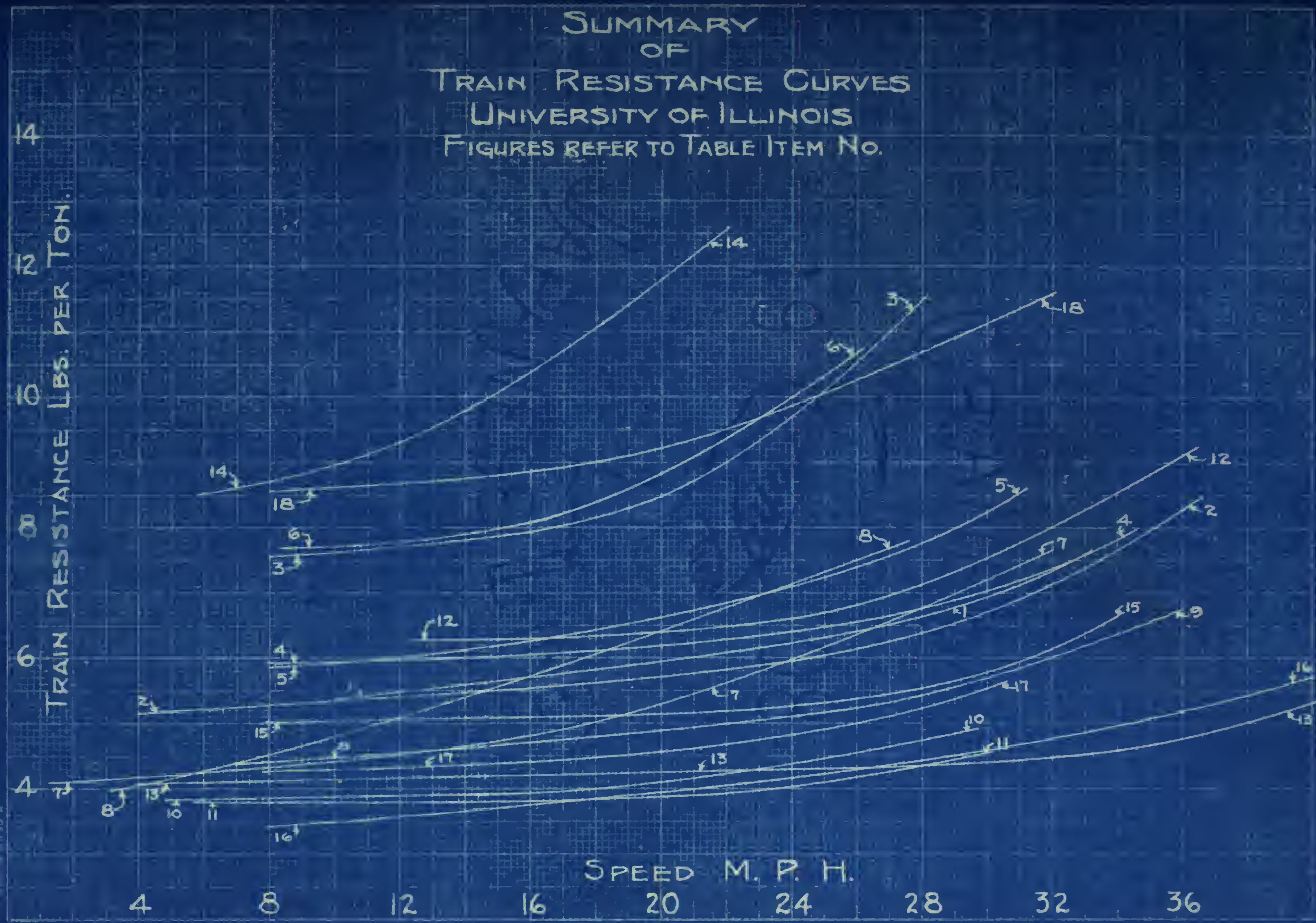
The curves given on page 3, showing the variation of train resistance with speed for trains of different loads per axle, may be considered as expressing the average results of all tests. The points for each one of them were obtained by taking the train resistance at a certain load per axle from each one of the curves shown on page 2. These points were then plotted with reference to speed, and the curve in question drawn through them.

## DISCUSSION OF RESULTS

An inspection of the Train Resistance - Load per axle curves on page 2, shows that, at a speed of 10 miles per hour, the train resistance for a train having a load per axle of 4 tons, which represents the conditions obtaining with an average train of empty cars, is 8.4 lbs. per ton and that this resistance decreases as the load per axle increases, until it reaches 3.8 lbs. per ton for a load per axle of 15 tons, which approximates the loading of an average train of loaded cars. In other words, the train resistance in pounds per ton, in the case of a train of empty cars, is more than double that in the case of a train of loaded cars.

It is not proposed here to attempt to account for this variation of train resistance with loading. However, a few words concerning it may not be out of place. C. A. Carus-Wilson in a paper entitled "The Pre-determination of Train Resistance" (Proceedings of the Institute of Civil Engineers, London, December 10, 1907) attributes it to truck action. However, it seems more probable that it is brought about by variations in journal friction. Beauchamp Tower, as a result of an exhaustive series of experiments,(Proceedings of the Institute of Mechanical Engineers, London, December 1883) says, "The coefficient of friction was found to vary nearly inversely as the load". If this statement is true, it explains admirably the fact that train resistance decreases as load per axle increases.

An inspection of the Summary of Train Resistance Curves, plotted from the Train Resistance - Load per Axle Curves, (see page 3), shows that, when the load per axle is low, the train resistance increases more rapidly as the speed increases, than when the load per axle is larger. This is probably due to the fact that air resistance constitutes a larger part of the total resistance when the load per axle is low than when it is large. The air resistance is the same for a train composed of any given number of cars, whether these cars are loaded or empty, and will therefore constitute a larger part of the total resistance when the cars are empty than when they are loaded. But air resistance increases very rapidly with speed, and the total resistance would therefore increase more rapidly as the speed increases when the load per axle is low than when it is large, which is shown plainly by the above mentioned curves.




SUMMARY
OF
TRAIN RESISTANCE CURVES
UNIVERSITY OF ILLINOIS
FIGURES REFER TO TABLE ITEM NO.

# TABLE
## TO ACCOMPANY
## SUMMARY OF TRAIN RESISTANCE CURVES
## UNIVERSITY OF ILLINOIS

| CURVE NO. | TEST NO. | TOTAL TONNAGE | NO. CARS | NO. LOADS | NO. EMPTIES | LOAD PER AXLE TONS |
|---|---|---|---|---|---|---|
| 1 | S-1013 | 2549 | 67 | 57 | 10 | 9.51 |
| 2 | S-1015 | 2489 | 69 | 61 | 8 | 9.02 |
| 3 | S-1016 | 1161 | 72 | 0 | 72 | 4.03 |
| 4 | S-1017 | 2532 | 66 | 53 | 13 | 9.61 |
| 5 | S-1018 | 1353 | 49 | 15 | 33 | 6.35 |
| 6 | S-1019 | 1572 | 89 | 14 | 75 | 4.43 |
| 7 | S-1021 | 2809 | 62 | 51 | 11 | 11.52 |
| 8 | S-1023 | 2243 | 58 | 41 | 17 | 9.68 |
| 9 | S-1027 | 2185 | 46 | 43 | 3 | 11.86 |
| 10 | S-1030A | 2035 | 34 | 32 | 2 | 14.95 |
| 11 | S-1030B | 2341 | 41 | 38 | 3 | 14.30 |
| 12 | S-1031 | 747 | 36 | 6 | 30 | 5.18 |
| 13 | S-1033 | 2275 | 44 | 42 | 2 | 12.93 |
| 14 | S-1034 | 1259 | 76 | 0 | 76 | 4.14 |
| 15 | S-1036 | 1961 | 52 | 44 | 8 | 9.43 |
| 16 | S-1038 | 2144 | 41 | 38 | 3 | 13.07 |
| 17 | S-1040 | 2152 | 47 | 45 | 2 | 11.44 |
| 18 | S-1043 | 1118 | 66 | 1 | 65 | 4.12 |

# APPENDIX A.

## METHODS OF CALCULATION

### DETERMINATION OF ACCIDENTAL RESISTANCES

GRADE RESISTANCE. - Grade is expressed either as feet of rise per mile of track or as percentage rise. In Figure 1, of this Appendix, the train is represented as being in equilibrium under the action of three forces, W its weight, r the normal reaction between rail and wheels, and the pull F. The pull F must equal the component c.

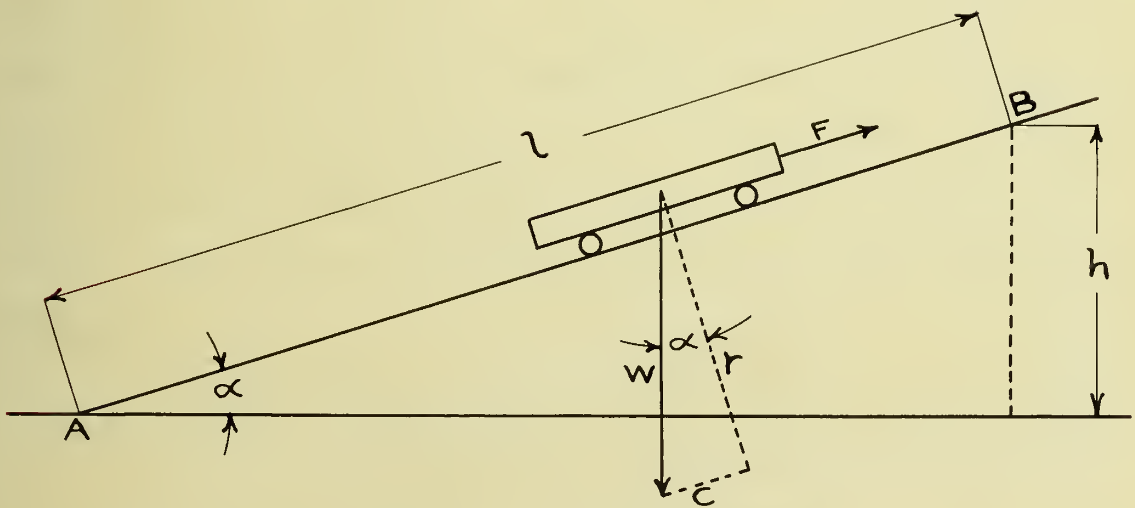



Figure 1

$$F = c = W \sin\alpha = W \times \frac{h}{l}$$

For a train of 1 ton moving on a grade of 1 foot per mile

$$W = 2000, \ h = 1 \text{ and } l = 5280$$

Whence $F = 2000 \times \frac{1}{5280} = 0.3788$ lbs.

Resistance = 0.379 lbs. per ton per foot per mile.

A one per cent grade is equivalent to grade of 52.8 ft. per mile.

And resistance for a 1% grade = 0.379 x 52.8 = 20.0 lbs. per ton.

ACCELERATION RESISTANCE.

In order to produce any change in speed, a certain force is necessary in addition to that required to overcome the true train resistance. This force necessary to produce acceleration may be divided into two parts, that necessary to produce acceleration of translation of the whole train and that necessary to produce acceleration of rotation of the wheels. The total acceleration resistance may be found as follows:-

Let $F_a$ = total force in lbs. required to produce accelerations, both of translation and rotation, for whole train.

$F$ = ditto for translation.

$f$ = " " rotation.

Then $F_a = F + f$.

To find F.

$$F = ma$$

Where $a$ = acceleration in feet per sec. per sec.

$m$ = mass of the train.

Let A = acceleration in miles per hour per second.

W = weight of train in tons.

$$\text{Then } a = \frac{A \times 5280}{60 \times 60} = 1.466A$$

$$m = \frac{W \times 2000}{32.2} = 62.11W$$

$$\therefore F = 1.466A \times 62.11W = 91.05\ AW$$

When A and W each = 1

F = 91.05 lbs.

To FIND f

Let O = angular acceleration of wheel.

a = tangentail acceleration at rim of wheel, in feet per second per second.

A = do, in miles per hour per second. This is the same as the acceleration of the train.

r = radius of wheel.

$r_K$= radius of gyration of one pair of wheels and axle.

I = moment of inertia of one pair of wheels and axle.

m = mass of one pair of wheels and axle.

$f_1$= force in pounds required to produce acceleration of rotation of one pair of wheels and axle.

M = moment of force to produce acceleration O.

Then we know that

$$M = IO = r_K^2 mO$$

And that $ro = a$ or $o = \frac{a}{r}$

Therefore $M = \dfrac{r_K^2}{r}\, ma$

And $f_1 = \dfrac{M}{r} = \left(\dfrac{r_K}{r}\right)^2 ma$

For ordinary car wheels $\dfrac{r_K}{r} = 0.64$

And the weight of an ordinary pair of car wheels and axle $= 1950$ pounds.

Making these substitutions:-

$$f_1 = (0.64)^2 \times \frac{1950}{32.2}\, a = 24.8\, a$$

Now $a = 1.466A$

And, since there are four pairs of wheels to each car

$$f = 4Nf_1$$

Where $N$ = number of cars in the train.

Making these substitutions:-

$$f = 4 \times 1.466 \times 24.8AN = 145.5AN$$

Therefore $F_a = 91.05AW + 145.5AN$

$= A(91.05W + 145.5N)$

Let $R_a$ = resistance due to acceleration of both rotation and translation, in pounds per ton.

Then $R_a = A(91.05 - 145.5\,\frac{N}{W})$

## CURVE AND WIND RESISTANCES

It is not possible to determine curve and wind resistances exactly. However, in these tests, curve resistance has been entirely eliminated by calculating the train resistance only where the whole train was on a tangent. The only way to eliminate wind resistance would be to run tests only on days when there was no wind, which would, of course, not be practical. However, the wind direction and velocity was recorded during each test here considered. From these data some idea may be gained as to the relative effect of the wind during the different tests.

## DETERMINATION OF TRUE TRAIN RESISTANCE

If the accidental resistances have been determined, it is possible to determine the "True Train Resistance". Two methods have been used, as explained below.

For all train-resistance determinations the data <u>must</u> include the following:-

Draw-bar pull

Speed

Profile and plan of track

Tonnage of train

Length of train

Number of cars

Pull and speed are usually expressed by curves drawn either on a distance or time base. Unless otherwise stated, a distance base is here assumed. Speed data may also be given in the shape of a time record on the dynamometer chart.

Observations ought also to be made of the direction and velocity of the wind and of the condition of the brakes in order to insure the absence of resistance due to these causes at the points or sections for which train resistance is to be calculated.

## FIRST OR "POINT" METHOD OF CALCULATION

The first method of calculation applies to cases where the data may all be determined with accuracy while the dynamometer car is passing a certain point on the road. Such points or stretches on the road should be selected at which it is certain that the entire train is on tangent track, either on a level or on a uniform grade and that the wind resistances are absent. Under these circumstances, the five elements of true resistance are in action and items 6 and 7 of the auxiliary resistances (grade and acceleration resistances) may also be operative. The following method of calculation is correct only under the assumptions made in this paragraph.

The notation used is as follows:-

P = total draw-bar pull - pounds

W = total weight of train - tons

$V$ = speed - miles per hour

$A$ = acceleration - miles per hour per second

$G$ = grade - feet per mile

$R$ = train resistance - lbs. per ton (item 1 to 5)

$R_g$ = resistance due to grade - lbs. per ton

$R_a$ = resistance due to acceleration - lbs. per ton

$T$ = gross resistance - pounds per ton - sum of all the acting resistances.

Then $T = \frac{P}{W} = R + R_a + R_g$

Therefore $R = T - R_a - R_g$

Now $T = \frac{P}{W}$ $\quad R_a = A(91.05 + 145.5 \frac{N}{W})$

And $R_g = 0.379\ G$

Therefore $R = \frac{P}{W} - A\ (91.05 + 145.5 \frac{N}{W}) - 0.379\ G$

ACCELERATION DETERMINATION.

Two methods of determining acceleration have been used. Both are given below.

METHOD NO. 1.

Let $s$ = distance in feet

$v$ = speed in feet per second

$a$ = acceleration in feet per second per second

$t$ = time in seconds

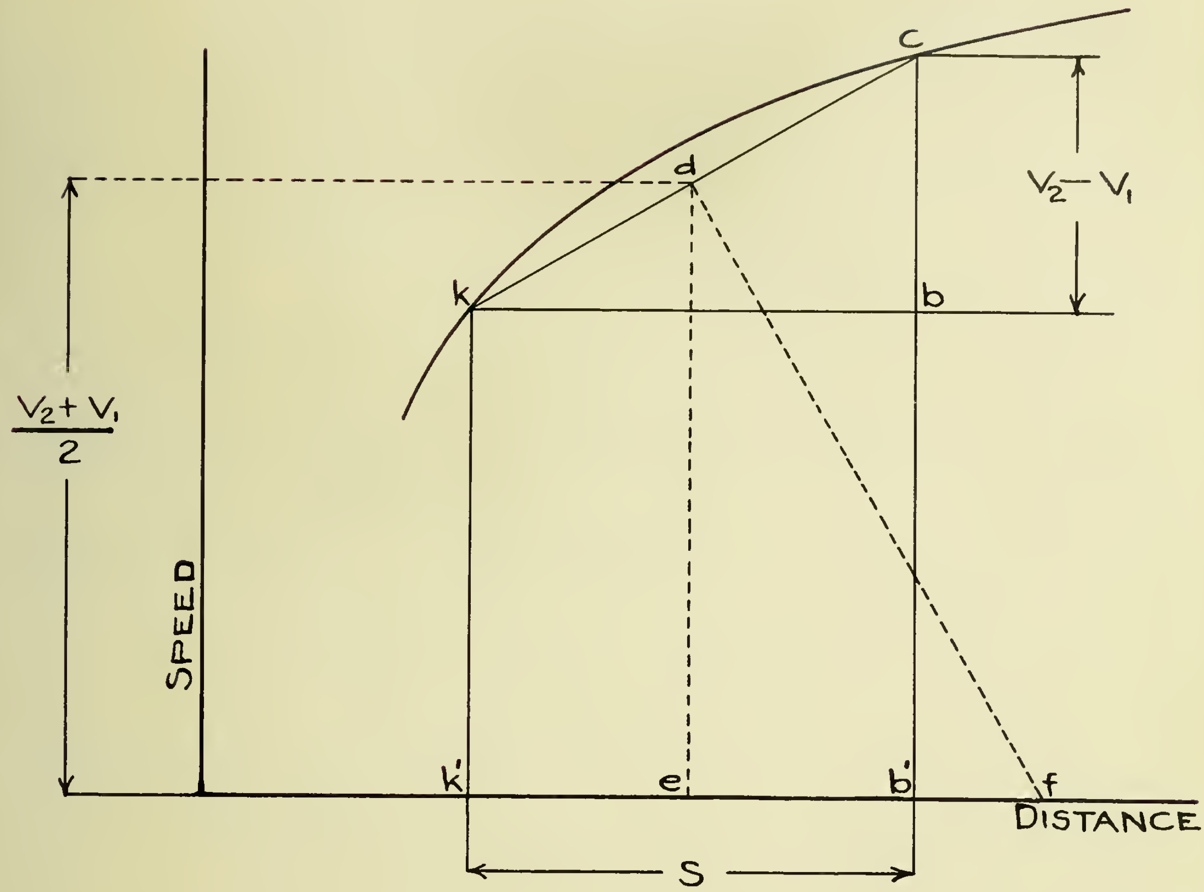



Figure 2

Let k and c ( see Figure 2 ) be two points on a speed curve drawn on a distance base. Then bc, the difference in the ordinates, represents the change in speed. Draw the straight line kc, bisect it by the line df at right angles, and draw de, perpendicular to the distance axis.

Then, since triangles kbc and def are similar,

$$\frac{ef}{de} = \frac{bc}{kb} \qquad \text{or } ef = \frac{bc \times de}{kb} \quad \text{- - - - - - - - - - - - -} \quad (1)$$

Assuming that the acceleration is uniform from k to c, let s be the distance passed over in time t, while the speed changes from $v_1$ to $v_2$. Then we know that

$$s = \frac{(v_2 + v_1)}{2} t \quad \text{or} \quad t = \frac{2s}{(v_2 + v_1)}$$

And $a = \frac{(v_2 - v_1)}{t}$

Therefore $a = \frac{(v_2 - v_1)}{\frac{2s}{(v_2 + v_1)}} = \frac{(v_2 - v_1)\ (v_2 + v_1)}{2s}$ - - (2)

But in the figure $(v_2 - v_1) = bc$

$$\frac{(v_2 + v_1)}{2} = de \qquad \text{and } s = kb$$

Substituting these values in (2)

$$a = \frac{bc \times de}{kb} = ef \quad \text{(see (1))} - - - - - - - (3)$$

Actually, of course, the acceleration may not be uniform. We may, however, take k indefinitely close to c, so that the line kc becomes a tangent to the speed curve, and df becomes a normal to that curve, while ef is a subnormal and represents the acceleration.

Thus we find that in the case of a speed curve drawn on a distance base, the subnormal at any point represents the acceleration at that point. It remains now, to determine the scale on which, for example, ef represents the acceleration at d.

Let the scale for speed be 1 inch = m feet per second, and the distance scale 1 inch = n feet. Let all distances be

measured in inches. Then, numerically

$$(v_2 - v_1) = bc \times m \text{ feet per second}$$

$$\frac{(v_2 + v_1)}{2} = de \times m \text{ feet per second}$$

$$\text{and} \quad s = kb \times n \text{ feet}$$

$$\text{Now} \quad a = \frac{(v_2 - v_1)\ (v_2 + v_1)}{2s}$$

$$\text{Therefore} \quad a = \frac{(bc \times m)\ (de \times m)}{kb \times n} = ef \times \frac{m^2}{n}$$

Let $A$ = acceleration in miles per hour per second.

Then $a = 1.468\ A$

Making this substitution

$$A = ef \times \frac{m^2}{1.466n} = .6818\ ef \times \frac{m^2}{n}$$

The above method of determining acceleration can be used only when the scale for speed is constant, i.e., when the calibration curve for the speed recorder is a straight line. Since the calibration curve of neither speed recorder on Test Car No. 17 is straight throughout the whole range of speed, but only over limited sections, it has not been possible to use this method in all cases. On this account the method given below was derived, and has been extensively used.

METHOD NO. 2.

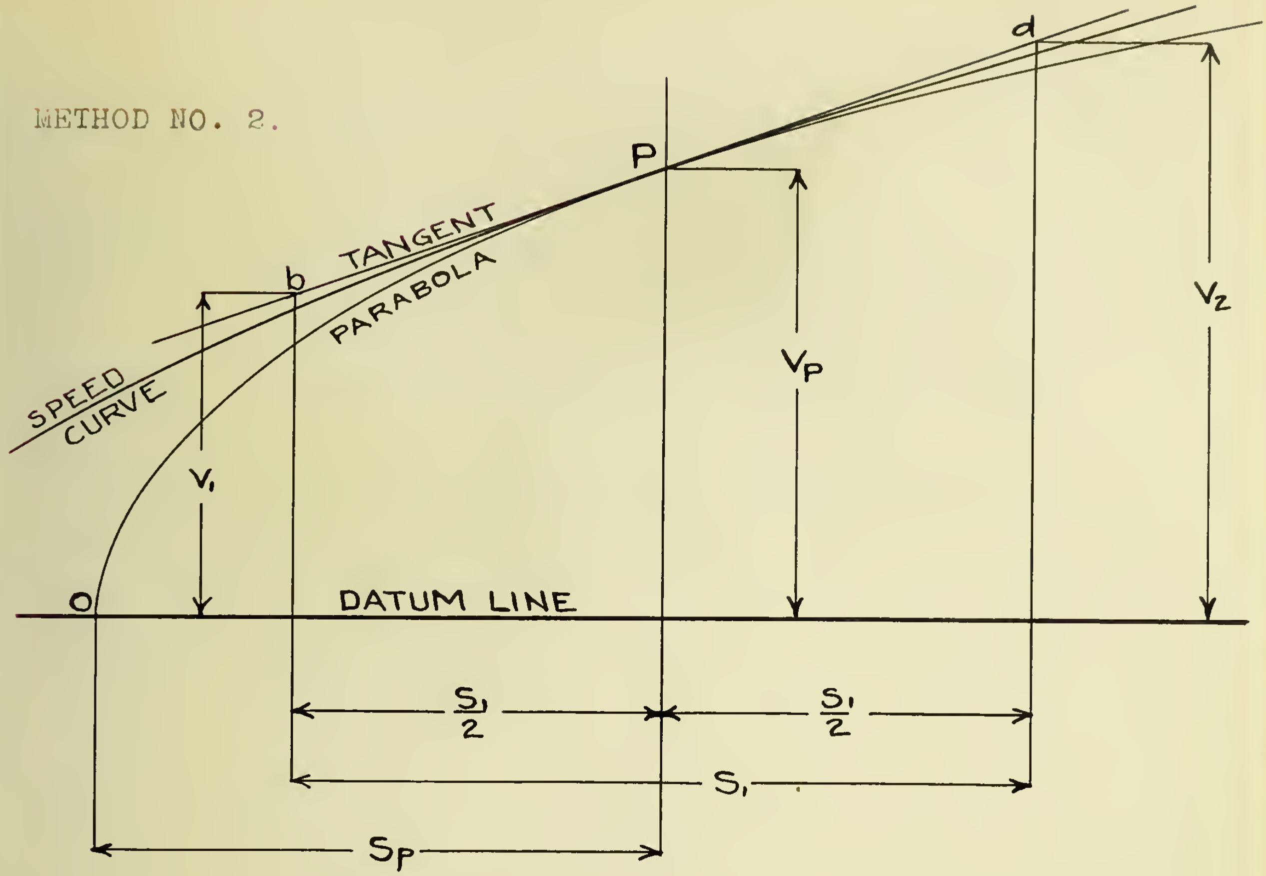



Figure 3

Assume that a parabola be passed through the point P of the speed curve (see Figure 3), tangent to this curve. Also draw a tangent to the speed curve at the same point. This will also be a tangent to the parabola. All those curves will coincide at the point P, and will therefore have the same acceleration at that point. Moreover for the parabola the acceleration will be the same anywhere, since it is the curve of constant acceleration. We may therefore, neglect the actual speed curve, and consider only the parabola and tangent. The equation for the parabola will be

$$v^2 = 2\ a\ s$$

Where $a$ = the acceleration

and $s$ = the distance from any point considered to the intersection of the parabola with datum line (measured parallel to the datum line)

Since the tangent has the same slope as the parabola at the point P, $\frac{dv}{ds}$ will be the same for both curves at that point.

Differentiating we have

$$2\ v\ dv = 2\ a\ ds$$

$$\frac{dv}{ds} = \frac{a}{v} \quad \text{and at P,} \quad \frac{dv}{ds} = \frac{a}{v_p}$$

Hence the equation of the tangent is

$$v = \frac{a}{v_p}\ s + K \qquad (1)$$

Now at point P, this equation must hold, hence

$$v_p = \frac{a}{v_p}\ s_p + K \quad \text{or } K = v_p - \frac{as_p}{v_p}$$

But $v^2_p = 2\ a\ s_p$ or $s_p = \frac{v_p^2}{2a}$

Therefore $K = v_p - \left(\frac{a}{v_p}\right)\left(\frac{v_p^2}{2a}\right) = \frac{v_p}{2}$

Substituting this value of K in (1) we get

$$v = \frac{a}{v_p}\ s + \frac{v_p}{2} \qquad (2)$$

as the equation of the tangent.

We will now consider a section whose length is $S_1$, so chosen that P is at its center.

Let $v_1$ = velocity to tangent at beginning of section.

$v_2$ = velocity to tangent at end of section.

Then $v_1 = \frac{a}{v_p}\left(S_p - \frac{S_1}{2}\right) + \frac{v_p}{2}$

But $S_p = \frac{v_p}{2a}$

Hence $v_1 = \frac{a}{v_p}\left(\frac{v_p^2}{2a} - \frac{s_1}{2}\right) + \frac{v_p}{2} = v_p - \frac{as_1}{2v_p}$

Likewise $v_2 = v_p + \frac{as_1}{2v_p}$

If now, we let $a_1$ = the constant or average acceleration which acting over the distance $s_1$ will cause the velocity to change from $v_1$ to $v_2$,

$$a_1 = \frac{v_2^2 - v_1^2}{2s_1} = \frac{(v_2 - v_1)(v_2 + v_1)}{2s_1}$$ (See page 29)

Substituting values just found for $v_2$ and $v_1$

$$a_1 = \frac{\left[\left(v_p + \frac{as_1}{2v_p}\right) - \left(v_p - \frac{as_1}{2v_p}\right)\right]\left[\left(v_p + \frac{as_1}{2v_p}\right) + \left(v_p - \frac{as_1}{2v_p}\right)\right]}{2\ s_1}$$

$$= \frac{\left(\frac{as_1}{v_p}\right)\left(2v_p\right)}{2\ s_1} = a.$$

That is, the constant or average acceleration, which acting over the section will cause the speed to change from $v_1$ to $v_2$ is the same as the acceleration of the parabola, and therefore the true acceleration at point P.

Stated in words, the second method of determining acceleration is, then, as follows:-

At the point where the acceleration is to be determined; draw a tangent to the speed curve. Lay off equal distances on each side of the point along the datum line, and measure the corresponding ordinates of the tangent at the beginning and end of the section thus laid out. If the velocities corresponding to these ordinates are $V_1$ and $V_2$ in miles per hour, and the length of the section is S ft., the acceleration at the point will be the same as that constant or average acceleration, which acting over the section will cause the speed to change from $V_1$ to $V_2$, and (as shown on page 29) will be, in miles per hour per second,

$$A = 0.733 \frac{V_2^2 - V_1^2}{S}$$

TRAIN RESISTANCE

SECOND OR "SECTION" METHOD OF CALCULATION.

In the first or "point" method of calculating true train resistance, the ability to determine all the data at a selected <u>point</u> on the dynamometer record is assumed. There

are cases, however, in which some of the data, particularly the acceleration, may not be accurately found at the point considered. In such cases, this second method of calculation offers a means of determining the resistance, in that it avoids the necessity for determining instantaneous acceleration. It is, in all respects similar to the first method, except that in it the values used for draw-bar pull, acceleration and grade, are the average values over a certain selected section, instead of being the instantaneous values at a certain selected point. The resistance determined by this method is then the average resistance over the section, and it applies to the average speed over the section.

SELECTING THE SECTION.

The section must be so selected that the following requirements are fulfilled:-

1. The track over the section, and for a distance equal to the length of the train before the entrance of the section, must be tangent.

2. The whole train must be on a uniform grade at the instant it enters and at the instant it leaves the section. However, the grade at entrance and at exit need not be the same.

3. The variations in speed over the section should not be great.

4. Wind resistance should be absent.

Having selected the section, it remains to determine the average pull, acceleration and grade. This may be done as follows:-

DETERMINATION OF AVERAGE PULL

In determining the average pull it is simply necessary to find the average ordinate of the pull curve, when the corresponding pull may be read from the calibration curve. This average ordinate may be found by dividing the area under the pull curve (determined by the use of the planimeter) by the length of the section measured on the dynamometer chart.

DETERMINATION OF AVERAGE ACCELERATION

Let $v_1$ and $v_2$ = the speeds at the entrance and exit of the section, in feet per second.

$V_1$ and $V_2$ = do, miles per hour.

s = length of the section in feet (measured along the track).

t = time to traverse section in seconds

a = average acceleration over section, in feet per second per second.

A = do, in miles per hour per second.

Then, we know that

$$v_2 = v_1 - at \quad \text{and that } s = v_1 t - 1/2\, at^2$$

Eliminating t between these two equations we get:

$$s = \frac{v_2^2 - v_1^2}{2a} \qquad \text{or} \qquad a = \frac{v_2^2 - v_1^2}{2s}$$

Now $a = 1.466\ A$

And $v = 1.466\ V$

Making these substitutions;

$$1.466\ A = \frac{(1.466)^2\ (V_2^2 - V_1^2)}{2s}$$

$$\text{or} \quad A = 0.733\ \frac{(V_2^2 - V_1^2)}{s}$$

DETERMINATION OF AVERAGE GRADE

Let $E_1$ and $E_2$ = elevations of the center of gravity of the train as it enters and leaves the section, in feet.

Then $E_2-E_1$ = the change in elevation in the distance, s.

And the average grade in feet per mile =

$$G = \frac{(E_2-E_1) \times 5280}{s}$$

If now we substitute these average values for acceleration and grade in the equation previously derived for determining train resistance by the first or "point" method, and remember that the pull is the average pull , to be found by means of a

planimeter, we shall have the equation for determining train resistance by the second or "section" method.

The equation as derived for method one, is;

$$R = \frac{P}{W} - A(91.05 + 145.5 \frac{N}{W}) - 0.379 G$$

After making the above substitutions the equation becomes;

$$R = \frac{P}{W} - 0.733 \frac{(V_2^2 - V_1^2)}{s} (91.05 + 145.5 \frac{N}{W}) - \frac{(E_2 - E_1) \times 5280 \times 0.379)}{s}$$

or

$$R = \frac{P}{W} - \frac{(V_2^2 - V_1^2)}{s} (66.7 + 106.6 \frac{N}{W}) - \frac{2001 (E_2 - E_1)}{s}$$

This equation gives the value of true train resistance at the average speed over the section.

## DETERMINATION OF WIND DIRECTION AND VELOCITY FROM DYNAMOMETER CAR NO. 17 CHART

Before discussing the method of determining the velocity and direction of the wind from the records obtained on the dynamometer chart, it will be well to consider the way in which these records are made.

### WIND VELOCITY RECORD

The wind velocity record is made by means of a Robinson

Cup annemometer, of the standard Weather Bureau type, supported on a bracket above the car, so that the cups are 2 feet 8 inches above the roof of the car. This annemometer is so constructed that an electric circuit is closed every time it registers .2 of a mile of wind, that is, every time .2 of a mile of wind has passed the car. In series with the circuit thus closed is an electro-magnet which controls an armature connected to the pen making the wind velocity record. This record then, consists of a line having offsets in it at intervals which represent .2 of a mile of wind. The time interval between these offsets which may be obtained from the time record on the chart, is a measure of the wind velocity relative to the car. This velocity may be determined as follows:-

Let $V_R$ = velocity of wind relative to car, in miles per hour.

$t$ = time in seconds between any two offsets in the wind velocity record. (Obtained from time record on chart)

$T$ = Do, in hours.

Then $T = \frac{t}{3600}$

And $V_R = \frac{3600}{5t} = \frac{720}{t}$

It should be noted that the velocity thus obtained

is the average velocity of the wind relative to the car over the time t.

WIND DIRECTION RECORD.

The wind direction record is made by a wind vane supported 3 feet above the car roof. The shaft from the wind vane projects down into the car carrying at its lower end a crank, which is parallel to the vane and points in the same direction as the arrow on the vane. The end of this crank rides in a slot in a piece fastened to the pen rod, as indicated in Figure 4. The datum or zero pen is so set that the line drawn by it and by the active pen coincide when the wind vane is pointing in a direction parallel to the axis of the car.

A commutator is placed on the wind vane shaft in such a manner that a brush riding on it makes a contact while the crank is pointing anywhere in the 180 degrees towards the front of the car. By the front of the car is meant the end on which the dynamometer cylinder is located. This commutator closes a circuit which throws an electro-magnet in parallel with the clock circuit. This electro-magnet actuates an armature which controls the datum line pen. Thus, when the wind vane is pointing towards the front end of the car (which may or may not be the front of the train) the datum line has a series of offsets in it at intervals of 5 seconds, and when the vane is pointing towards the back of the car, the datum line is without offsets.

DETERMINATION OF ABSOLUTE DIRECTION AND VELOCITY OF THE WIND.

We will suppose that it is desired to find the absolute direction and velocity of the wind at point A - A, Figure 4. From O as a center with a radius of 1-1/4 inches, which is the length of the crank at the bottom of the wind vane shaft, describe an arc intersecting the datum line at b and at c. We know then, that the direction of the wind relative to the car is either Ob or Oc. Now there are no offsets in the datum line at A - A, which shows that the wind is coming from the back of the car. But the paper always travels away from the pens towards the back of the car, as shown by the arrow. Therefore the direction of the wind relative to the car is from O to b. That is, at the time the active pen was at O, the crank was in the position shown dotted in the figure.

Having determined the relative direction of the wind, the next step is to determine its relative velocity, which may be done as explained under "Wind Velocity Record" above. We then draw de Figure 5, parallel to ob and of such a length that this length represents to some scale the relative velocity which we have just found. We must then find from the speed record, the speed of the car, and from either the log book or the stamp at the end of the record, whether the car is running forwards or backwards. Assume in this case that it is running forwards. We then draw ef parallel to the motion of the train in direction, and of such a length that

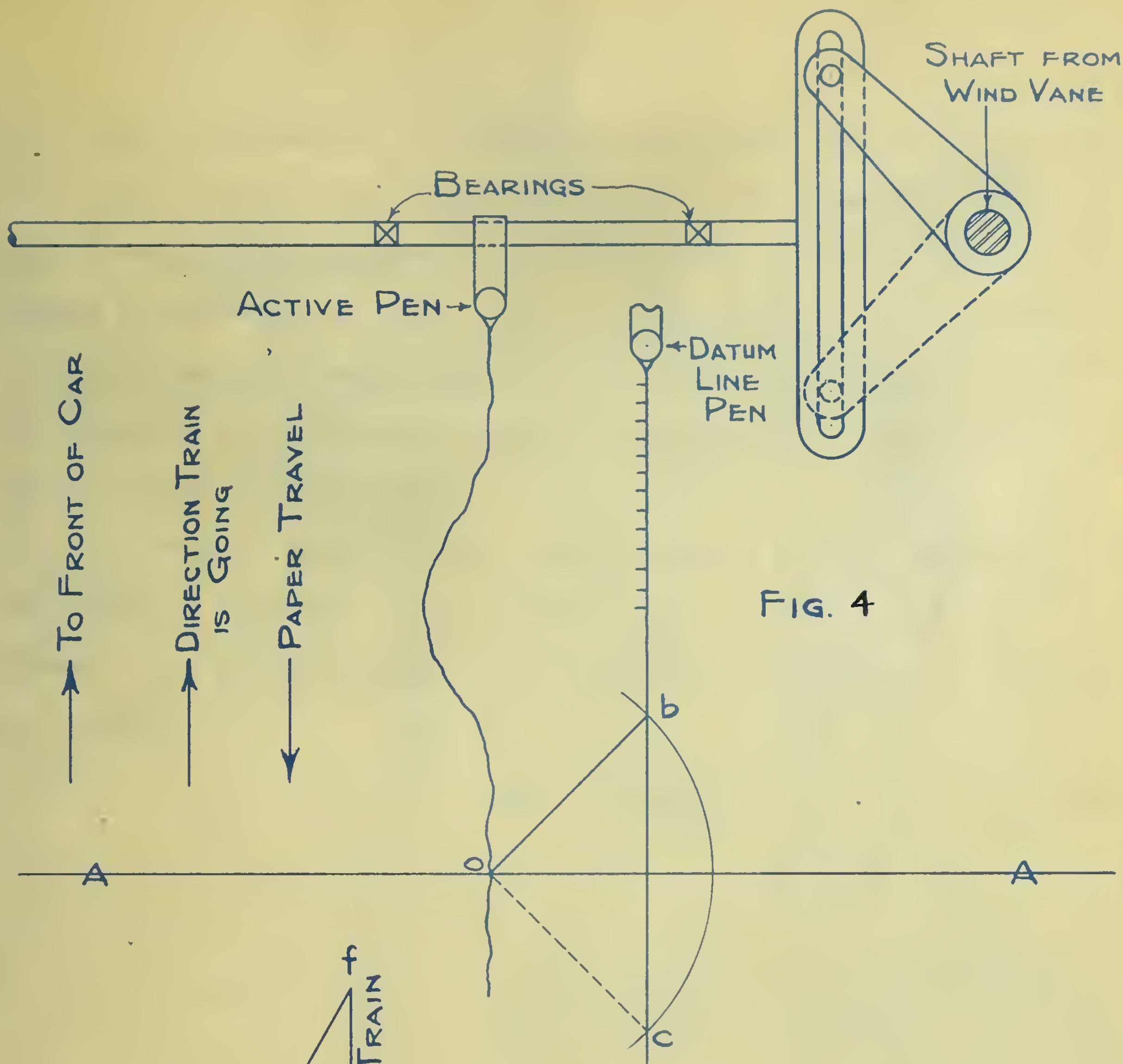



Fig. 4

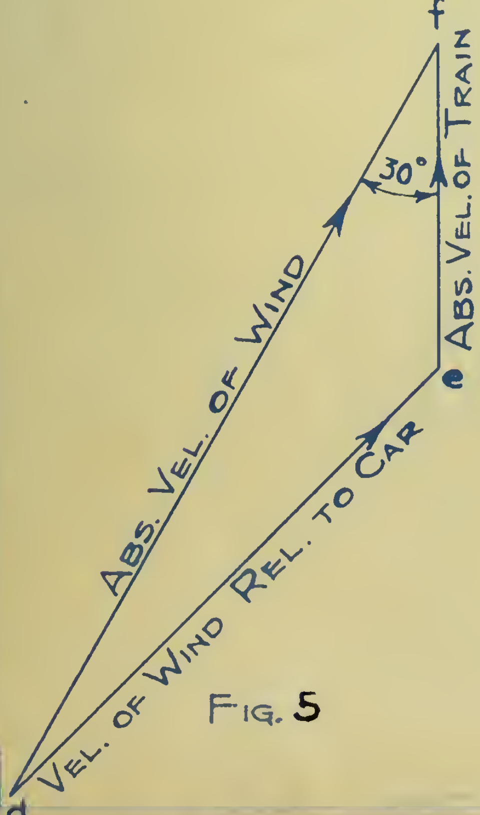



Fig. 5

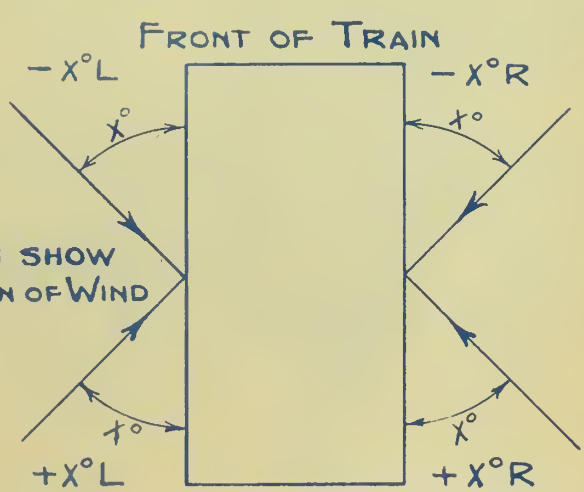



Fig. 6
Method used in Designating
Direction of Wind

its length represents, to the selected scale, the speed of the train. Care must be taken to have this line so drawn that the arrows representing the direction of motion shall follow around from d to f. The closing side of the triangle, df, will then represent, in direction and in magnitude, the absolute direction and velocity of the wind, the direction being as shown by the arrows.

Figure 6 shows the method adopted for designating the absolute wind direction. Thus, in the above case, if the angle dfe is 30 degrees, the designation for this wind would be, $+30^{\circ}$L.

# Appendix B

## Observed and Calculated Data.

All dynamometer charts, tonnage records and other original data, as well as all notes and calculations made in connection with the tests here reported, are on filo in the office of the Railway Engineering Department of the University of Illinois. All calculations were made with great care, and were checked in most cases by a different person than the one who originally made them. Every precaution was taken against numerical errors, and it is believed that this work is fairly free from them.

In the following pages will be found observed and calculated data concerning each test. The calculated data is expressed both in the form of tables and in the form of curves. After the calculations were first made they were very carefully studied, and wherever the data was at all incomplete, or where there were uncertainties in connection with it, the calculations were discarded. For this reason there are many missing numbers in the column headed "Item Number", these missing numbers representing calculations which were rejected for the above mentioned reasons.

TEST NO. S - 1013.

From Champaign to Gilman - April 27, 1908.

Freight train No. Extra 940 - North. Engine No. 940.

300 Pound Spring. 1/2 square inch Piston Area.

Total weight behind measuring draw-bar, 2549 tons,including No.17.

Train length 2850 ft. Number of Cars 67, Empties 10, Loads 57.

Weight per axle 9.51 tons.

Kind of cars: 47 box 9 Gondola 6 Refrigerator 3 Tank

1 Caboose 1 Test.

Weather: Wet, raining at intervals. Temperature 42° F. at

start, 44° F. at end of test.

TEST NO. S - 1013

METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 Item No. | 2 Location Mile Post Number | 3 Total Draw-bar Pull Pounds P | 4 Acceleration Miles per Hour per Second A | 5 Grade Ft. per Mile + Up - Down G | 6 Curvature | 7* Wind Direction | 8 Wind Velocity M.P.H. | 9 Speed of Train M.P.H. | 10 Net Train Resistance Lbs. per Ton R |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 116.67 | 16400 | 0 | +1.48 | 0 | +52°L | 18.0 | 18.2 | 5.86 |
| 3 | 112.23 | 13750 | 0 | -2.78 | 0 | 90°L | 18.9 | 24.3 | 6.45 |
| 4 | 110.46 | 29600 | 0 | +16.50 | 0 | 90°L | 18.9 | 11.5 | 5.34 |
| 5 | 108.80 | 11900 | 0 | -4.82 | 0 | +38°L | 24.5 | 24.6 | 6.50 |
| 7 | 105.86 | 9850 | 0 | -10.00 | 0 | +50°L | 22.0 | 32.7 | 7.65 |
| 8 | 100.51 | 23000 | 0 | +8.52 | 0 | 90°L | 16.7 | 12.7 | 5.79 |
| 9 | 99.29 | 12750 | 0 | -5.74 | 0 | +35°L | 20.5 | 27.5 | 7.18 |
| 10 | 91.00 | 12500 | 0 | -2.59 | 0 | +53°L | 14.5 | 26.3 | 5.89 |
| 11 | 90.08 | 12550 | +.028 | -9.32 | 0 | +55°L | 26.5 | 27.5 | 5.81 |
| 12 | 87.00 | 13100 | 0 | -2.23 | 0 | +44°L | 17.2 | 24.1 | 5.99 |
| 13 | 86.15 | 15300 | 0 | 0.00 | 0 | 90°L | 17.1 | 20.7 | 6.00 |
| 14 | 84.46 | 16400 | -.020 | +6.20 | 0 | 90°L | 14.4 | 18.4 | 6.00 |
| 15 | 83.24 | 12250 | 0 | -5.00 | 0 | 90°L | 20.6 | 25.1 | 6.71 |
| 16 | 81.86 | 13000 | 0 | -1.67 | 0 | 90°L | 14.4 | 16.0 | 5.73 |

* See page 35 Appendix A.

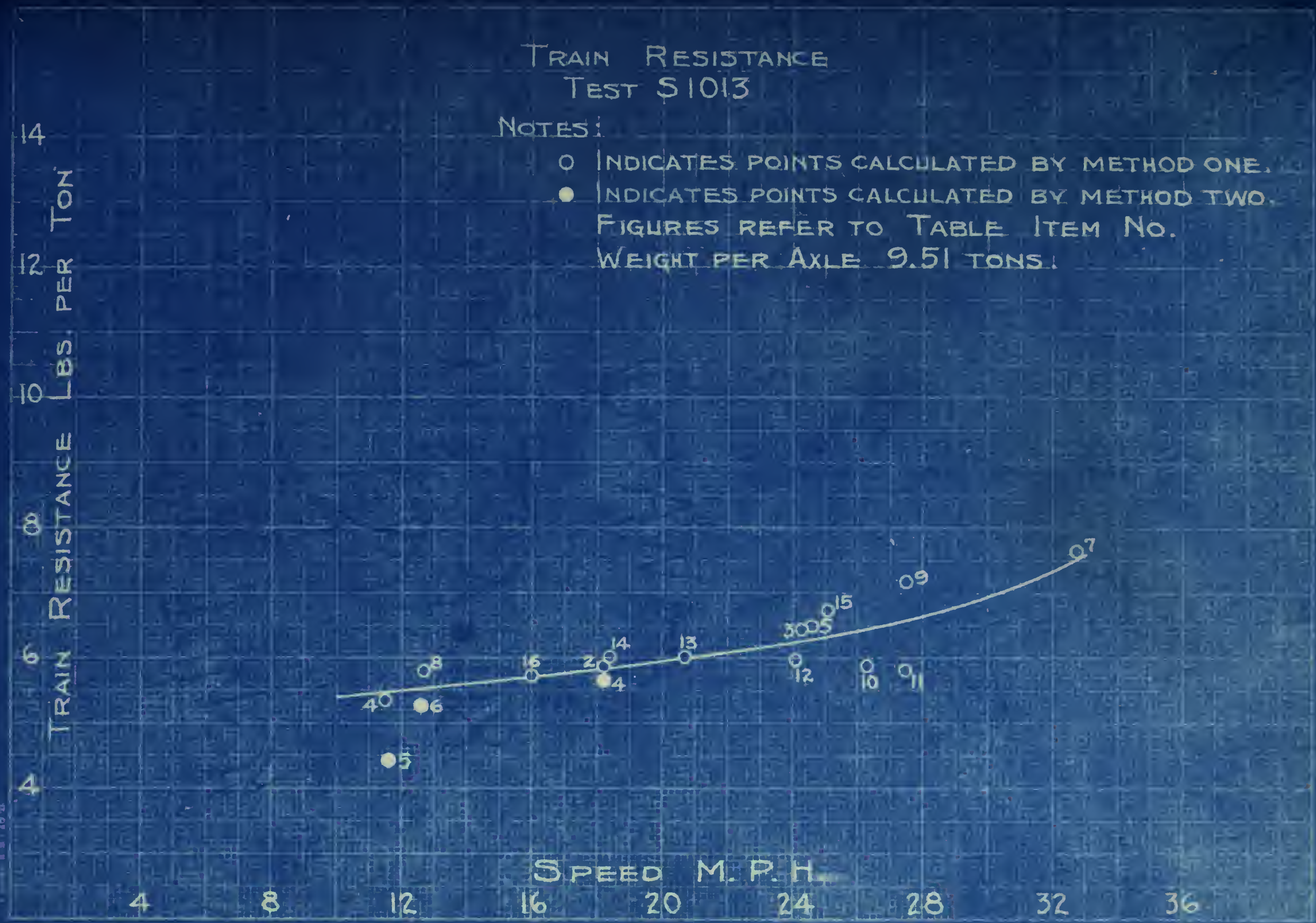
TEST NO. S - 1013

METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS 1425 FT. BACK OF HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft. S | Total Mean Draw-Bar Pull Lbs. P | Speed at Entrance M.P.H. $V_1$ | Speed at Exit M.P.H. $V_2$ | Avg. Speed M.P.H. V | Grade Ft. per mile + Up -Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 4 | 116.25-117.00 | 3960 | 16400 | 18.2 | 18.2 | 18.2 | +2.00 | 0 | $+52^{\circ}L$ | 18.0 | 5.68 |
| 5 | 110.46-111.00 | 2870 | 30000 | 11.6 | 11.6 | 11.6 | +19.32 | 0 | $90^{\circ}L$ | 18.9 | 4.45 |
| 6 | 100.82-101.55 | 3880 | 23700 | 12.6 | 12.6 | 12.6 | +10.60 | 0 | $90^{\circ}L$ | 16.7 | 5.29 |

* See page 35 Appendix A.


TRAIN RESISTANCE
TEST S1013
NOTES:
○ INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM No.
WEIGHT PER AXLE 9.51 TONS.
TRAIN RESISTANCE LBS. PER TON
14
12
10
8
6
4
SPEED M.P.H.
4
8
12
16
20
24
28
32
36
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

TEST NO. S - 1015.

From Champaign to Gilman - April 29, 1908.

Freight train No. Extra 921 - North. Engine No. 921.

300 Pound Spring. 1/2 square inch Piston Area.

Total weight behind measuring draw-bar, 2489 tons, excluding No.17.

Train length, 2520 ft. Number of Cars, 69 Empties 8 Loads 61.

Weight per axle 9.02 tons.

Kind of cars: 46 Box 4 Gondola 7 Tank 11 Flat 1 Caboose.

Weather: Cloudy but dry. Temperature 40°F., at start,

48° F., at end of test.

T E S T   N O. S - 1015

METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location: Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration Miles per Hour per Second A | Grade Ft. per Mile + Up − Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 5 | 114.35 | 21800 | 0 | +7.96 | 0 | -78°L | 6.0 | 13.9 | 5.84 |
| 6 | 112.27 | 14800 | 0 | -3.56 | 0 | -50°L | 9.7 | 23.0 | 7.30 |
| 7 | 110.64 | 31000 | 0 | +20.50 | 0 | -63°L | 7.0 | 7.0 | 4.68 |
| 8 | 108.67 | 13900 | -0.022 | +4.39 | 0 | -59°L | 9.0 | 24.5 | 6.02 |
| 9 | 105.95 | 10500 | +0.022 | -15.04 | 0 | -39°L | 15.0 | 31.77 | 7.80 |
| 10 | 101.76 | 11600 | 0 | - 1.47 | 0 | -27°L | 12.1 | 22.1 | 5.23 |
| 11 | 100.49 | 18500 | 0 | +4.82 | 0 | -54°L | 6.4 | 16.4 | 5.61 |
| 12 | 96.94 | 3750 | 0 | -16.55 | 0 | -37°L | 15.2 | 32.1 | 7.79 |
| 13 | 96.0 | 5500 | +0.062 | -27.0 | 0 | -45°L | 15.0 | 33.1 | 8.51 |
| 14 | 95.48 | 3500 | +0.030 | -24.0 | 0 | -54°L | 10.8 | 36.4 | 7.65 |
| 15 | 94.00 | 5250 | 0 | -13.20 | 0 | -32°L | 16.3 | 31.25 | 7.11 |
| 16 | 92.00 | 5500 | 0 | -11.30 | 0 | -60°L | 6.8 | 29.50 | 6.50 |
| 17 | 90.00 | 7750 | 0 | -8.80 | 0 | -78°L | 12.5 | 28.25 | 6.44 |
| 18 | 86.00 | 12500 | 0 | -1.05 | 0 | +81°L | 10.3 | 21.00 | 5.42 |
| 19 | 103.44 | 25800 | -0.0587 | +30.60 | 0 | -34°L | 10.0 | 13.90 | 4.35 |
| 20 | 103.35 | 28000 | -0.0587 | +31.60 | 0 | -27°L | 8.3 | 12.00 | 4.84 |
| 21 | 103.25 | 31600 | -0.0587 | +33.00 | 0 | -26°L | 5.6 | 9.70 | 5.69 |
| 22 | 103.02 | 36750 | -0.014 | +29.70 | 0 | -65°L | 2.0 | 5.28 | 4.85 |

* See page 35, Appendix A.

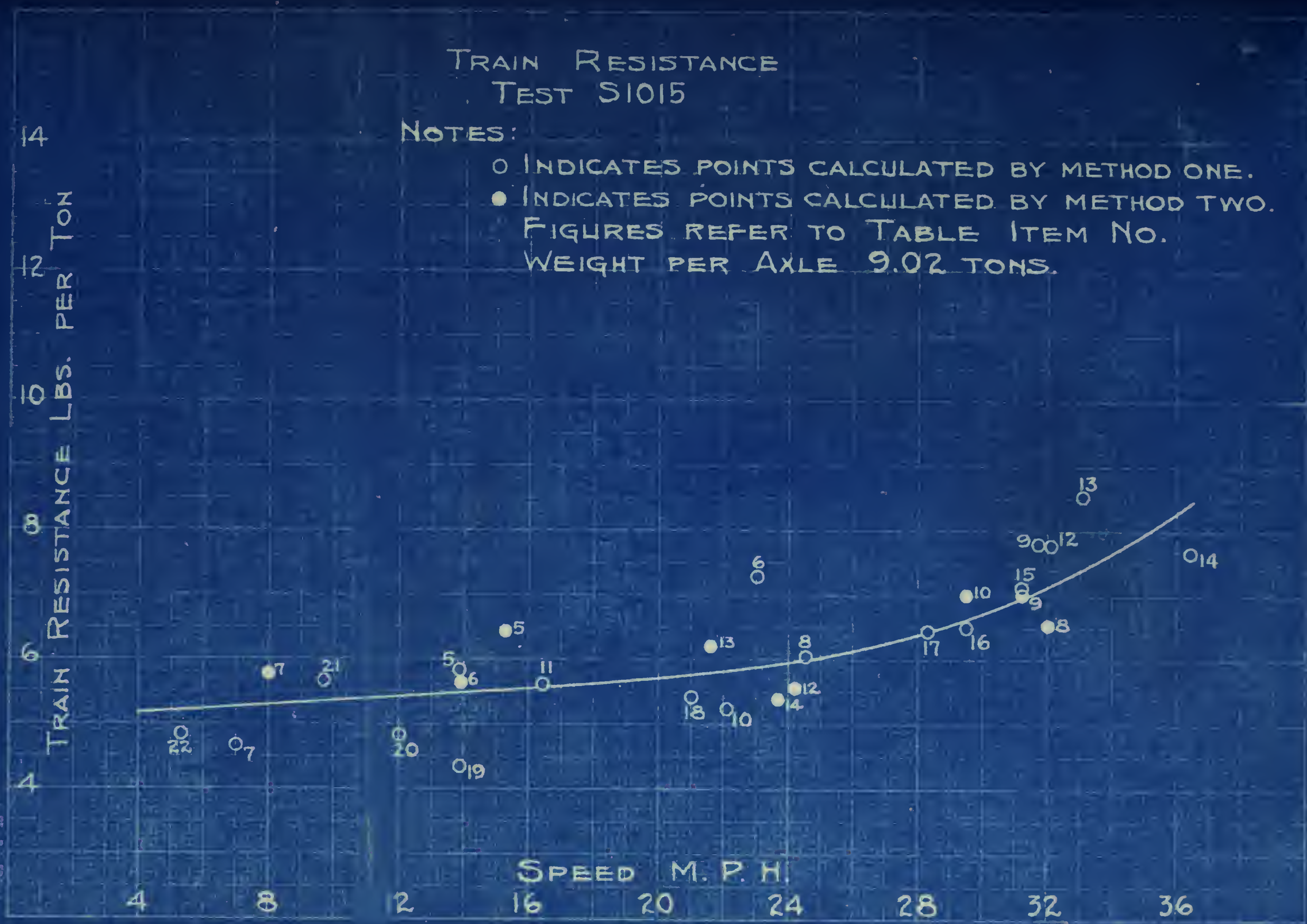
## T E S T N O. S - 1015

### METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS 1200 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft. S | Total Mean Draw-Bar Pull Lbs. P | Speed at Entrance M.P.H. $V_1$ | Speed at Exit M.P.H. $V_2$ | Avg. Speed M.P.H. V | Grade: Ft. per Mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 6 | 114.81-114.18 | 3310 | 22200 | 13.9 | 13.9 | 13.9 | +8.62 | 0 | $-78^{\circ}$L | 6.0 | 5.66 |
| 7 | 111.22-110.58 | 3380 | 31500 | 9.0 | 7.0 | 8.0 | +19.82 | 0 | $-63^{\circ}$L | 7.0 | 5.80 |
| 8 | 97.16-96.19 | 5160 | 5250 | 31.4 | 31.7 | 32.0 | -12.38 | 0 | $-54^{\circ}$L | 10.8 | 6.51 |
| 9 | 94.18-93.54 | 3420 | 5250 | 31.2 | 31.2 | 31.2 | -12.96 | 0 | $-32^{\circ}$L | 16.3 | 7.03 |
| 12 | 88.14-87.12 | 5380 | 10000 | 24.2 | 24.2 | 24.2 | -4.12 | 0 | $-42^{\circ}$L | 10.3 | 5.58 |
| 13 | 86.31-85.44 | 4650 | 12500 | 21.5 | 21.7 | 21.6 | -3.52 | 0 | $+81^{\circ}$L | 10.3 | 6.21 |

* See page 35, Appendix A.


TRAIN RESISTANCE
TEST S1015
NOTES:
o INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE 9.02 TONS.
TRAIN RESISTANCE LBS. PER TON
SPEED M. P. H.
4
6
8
10
12
14
4
8
12
16
20
24
28
32
36

TEST NO. S - 1016.

From Gilman to Champaign - April 30, 1908.

Freight train No. Extra 581 - South. Engine No. 581.

300 Pound Spring. 1/2 square inch Piston Area.

Total weight behind measuring draw-bar, 1161 tons, including No.17.

Train length, 3030 ft. Number of Cars, 72. Empties 72 Loads 0.

Weight per axle 4.03 tons.

Kind of Cars: All empty coal cars.

Weather: Cloudy. Temperature 44° F., at start. 48° F., at end of test.

TEST NO. S - 1016

METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 9 | 94.57 | 14400 | 0 | +12.21 | 0 | +55°R | 13.7 | 11.2 | 7.77 |
| 10 | 95.55 | 10450 | 0 | +5.06 | 0 | +58°R | 10.0 | 16.3 | 7.08 |
| 11 | 96.91 | 20250 | 0 | +25.80 | 0 | +55°R | 10.0 | 9.5 | 7.66 |
| 12 | 98.67 | 21500 | 0 | +28.80 | 0 | +57°R | 6.0 | 8.3 | 7.60 |
| 15 | 105.66 | 6250 | -0.0118 | -8.20 | 0 | +31°R | 12.0 | 24.1 | 9.74 |
| 16 | 106.27 | 9250 | -0.030 | -4.44 | 0 | +34°R | 10.5 | 22.9 | 9.28 |
| 17 | 106.91 | 13600 | -0.0117 | +13.25 | 0 | +35°R | 7.4 | 17.1 | 7.85 |
| 18 | 107.39 | 14750 | -0.0117 | +17.40 | 0 | +28°R | 9.8 | 16.6 | 7.27 |
| 19 | 107.75 | 14700 | -0.0117 | +16.20 | 0 | +23°R | 9.2 | 15.0 | 7.67 |
| 21 | 115.89 | 7500 | 0 | -7.32 | 0 | +22°R | 9.4 | 23.6 | 9.23 |
| 22 | 117.65 | 8000 | 0 | -1.57 | 0 | +22°R | 8.6 | 21.3 | 7.48 |
| 23 | 109.22 | 9900 | 0 | -1.92 | 0 | +28°R | 10.6 | 20.1 | 9.26 |
| 24 | 99.705 | 8750 | 0 | -4.87 | 0 | +20°R | 15.1 | 18.9 | 9.38 |

*See Page 35, Appendix A

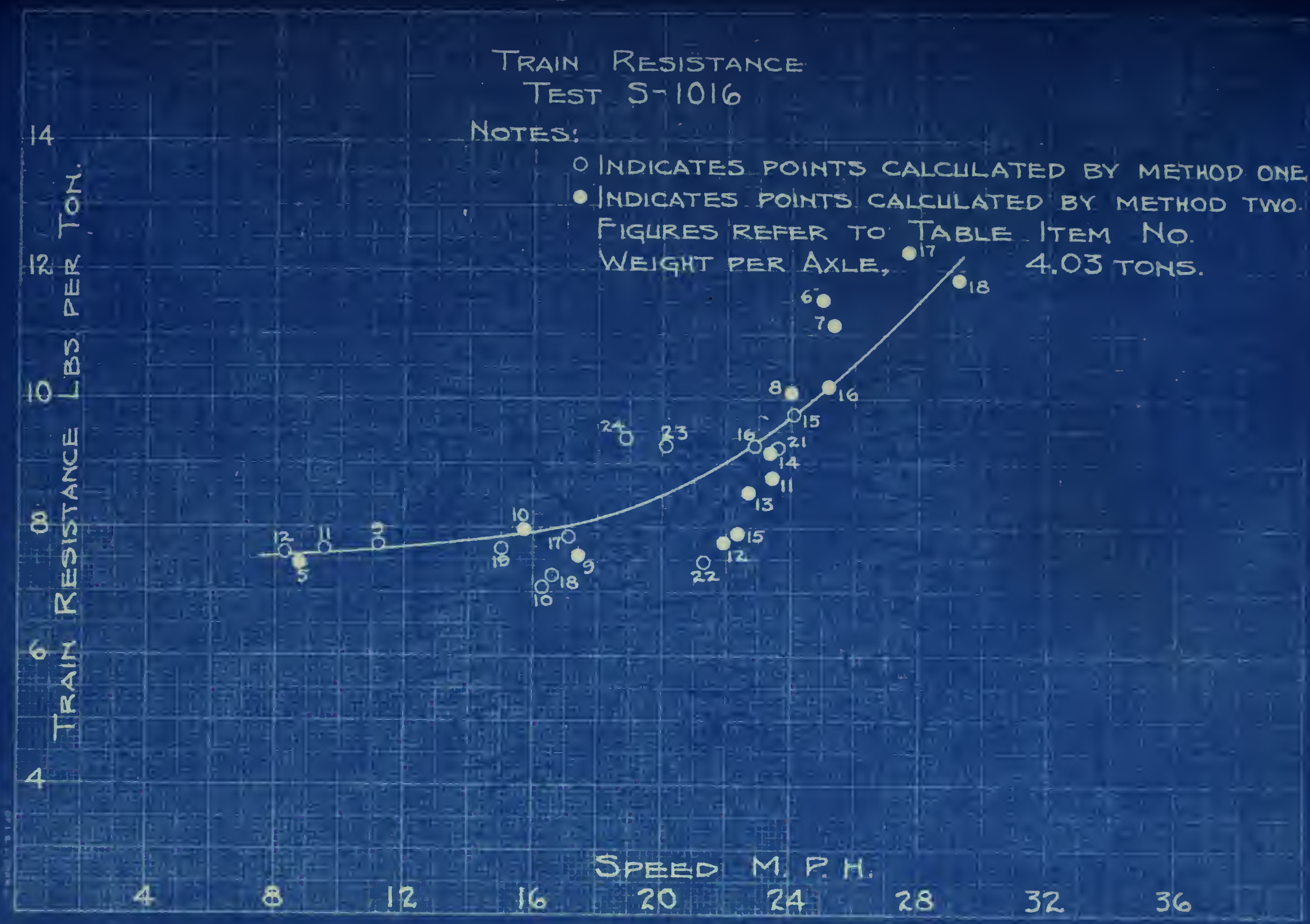
# T E S T  N O. S - 1016

## METHOD TWO - TRAIN RESISTANCE OVER A SECTION

### CENTER OF MASS 1515 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft. S | Total Mean Draw-Bar Pull Lbs. P | Speed at Entrance M.P.H. V1 | Speed at Exit M.P.H. V2 | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 5 | 98.23-98.85 | 3280 | 21000 | 9.25 | 7.40 | 8.75 | +29.90 | 0 | +57°R | 6.0 | 7.43 |
| 6 | 104.37-104.88 | 2675 | 6000 | 25.00 | 25.00 | 25.00 | -16.78 | 0 | +41°R | 10.1 | 11.52 |
| 7 | 105.17-105.66 | 2596 | 6200 | 25.65 | 24.53 | 25.30 | -11.30 | 0 | +41°R | 10.8 | 11.15 |
| 8 | 105.66-106.27 | 3208 | 8400 | 24.28 | 22.90 | 24.00 | -3.62 | 0 | +31°R | 12.0 | 10.10 |
| 9 | 106.91-107.37 | 2430 | 14000 | 18.20 | 16.60 | 17.40 | +14.13 | 0 | +35°R | 7.4 | 7.56 |
| 10 | 107.37-107.75 | 2030 | 14300 | 16.60 | 14.90 | 15.70 | +16.65 | 0 | +28°R | 9.8 | 7.96 |
| 11 | 115.65-116.15 | 2640 | 7400 | 23.30 | 23.30 | 23.40 | -6.40 | 0 | +22°R | 9.4 | 8.79 |
| 12 | 116.68-117.65 | 5120 | 7750 | 22.50 | 21.40 | 21.95 | -2.68 | 0 | +22°R | 8.6 | 7.77 |
| 13 | 118.17-120.37 | 11570 | 10250 | 22.00 | 23.30 | 22.65 | -0.14 | 0 | +15°R | 10.5 | 8.51 |
| 14 | 120.33-121.64 | 6950 | 10000 | 23.30 | 24.20 | 23.75 | -2.58 | 0 | +37°R | 8.0 | 9.13 |
| 15 | 125.20-125.07 | 9880 | 10200 | 22.30 | 22.30 | 22.30 | -0.27 | 0 | +33°R | 9.0 | 9.90 |
| 16 | 111.45-111.79 | 1752 | 6600 | 24.16 | 26.15 | 25.15 | -22.90 | 0 | - | - | 10.18 |
| 17 | 111.79-112.28 | 2604 | 6500 | 26.15 | 29.10 | 27.65 | -29.65 | 0 | - | - | 12.26 |
| 18 | 112.28-112.62 | 600 | 3500 | 29.17 | 29.42 | 29.20 | -28.20 | 0 | - | - | 11.87 |

* See page [illegible]5, Appendix A


TRAIN RESISTANCE
TEST S-1016
NOTES:
○ INDICATES POINTS CALCULATED BY METHOD ONE
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE, 4.03 TONS.
TRAIN RESISTANCE LBS PER TON.
SPEED M. P. H.

TEST NO. S - 1017

From Champaign to Gilman - May 1, 1908.

Freight train No. Extra 920 - North. Engine No. 920.

300 Pound Spring. 1/2 square inch Piston Area.

Total weight behind measuring draw-bar, 2532 tons, excluding No. 17.

Train length, 2670 ft. Number of Cars, 66. Empties 13 Loads 53.

Weight per axle, 9.61 tons.

Kind of Cars: 59 Box 3 Gondola 3 Refrigerator 1 Caboose.

Weather: Unsettled with rain at intervals. Temperature 46°F., at start, 54°F., at end of test.

## T E S T N O. S - 1017

### METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location: Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration: Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 2 | 85.23 | 11250 | 0 | -3.71 | 0 | +74°L | 18 | 20.6 | 5.86 |
| 3 | 86.16 | 14700 | 0 | 0 | 0 | +72°L | 16 | 18.5 | 5.81 |
| 4 | 88.12 | 10000 | 0 | -6.45 | 0 | -65°L | 18 | 22.0 | 6.40 |
| 5 | 90.00 | 6500 | 0 | -8.47 | 0 | +49°L | 37 | 24.0 | 5.88 |
| 6 | 91.25 | 5750 | 0 | -8.54 | 0 | -66°L | 19 | 27.5 | 5.51 |
| 8 | 95.82 | 5850 | +0.0465 | -24.35 | 0 | +84°L | 13 | 31.5 | 7.14 |
| 9 | 100.71 | 25300 | 0 | +8.90 | 0 | +61°L | 22 | 11.0 | 6.62 |
| 10 | 101.48 | 21900 | -0.0101 | +10.20 | 0 | +89°L | 14 | 11.35 | 5.84 |
| 11 | 103.69 | 29000 | -0.0500 | +27.80 | 0 | +70°L | 14 | 10.5 | 6.14 |
| 12 | 103.60 | 30100 | -0.0545 | +28.90 | 0 | +73°L | 13 | 10.0 | 6.11 |
| 13 | 103.89 | 25500 | -0.0500 | +22.60 | 0 | +72°L | 16 | 14.0 | 6.20 |
| 14 | 104.53 | 19900 | -0.0388 | +15.50 | 0 | -84°L | 15 | 16.9 | 5.66 |
| 15 | 104.41 | 21850 | -0.0388 | +15.64 | 0 | -83°L | 12 | 15.8 | 6.38 |
| 16 | 105.71 | 12250 | 0 | -4.05 | 0 | -84°L | 10 | 27.2 | 6.37 |
| 17 | 106.30 | 14250 | +0.0325 | -12.10 | 0 | - | - | 25.3 | 7.14 |
| 18 | 106.00 | 12750 | +0.0325 | -14.72 | 0 | +59°L | 11 | 27.0 | 7.53 |
| 19 | 96.00 | 5350 | +0.0550 | -27.05 | 0 | -78°L | 10 | 30.3 | 7.14 |
| 20 | 95.65 | 3500 | -0.0425 | -28.70 | 0 | +80°L | 17 | 32.5 | 8.25 |

* See page 3‾, Appendix A.

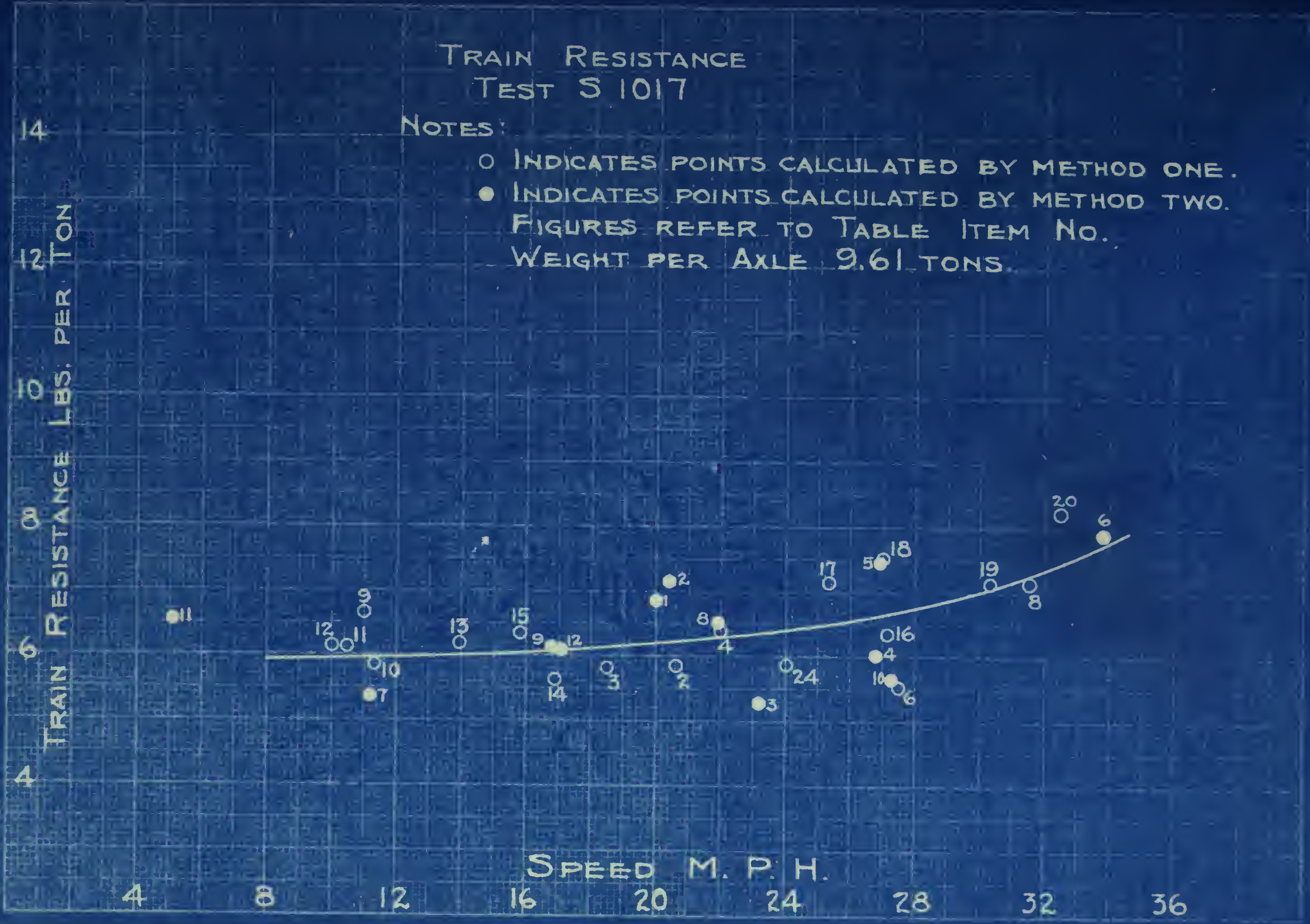
## T E S T  N O. S - 1017

### METHOD TWO - TRAIN RESISTANCE OVER A SECTION

### CENTER OF MASS 1200 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft. S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. $V_1$ | Speed at Exit M.P.H. $V_2$ | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up -Down | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 1 | 82.41-82.00 | 2152 | 17300 | 20.10 | 19.40 | 20.00 | +2.20 | 0 | +47°L | 8 | 6.89 |
| 2 | 87.56-86.80 | 4348 | 16100 | 22.10 | 21.32 | 20.40 | -0.66 | 0 | +65°L | 12 | 7.15 |
| 3 | 89.10-88.59 | 2372 | 9000 | 23.40 | 22.70 | 23.20 | -1.90 | 0 | +52°L | 21 | 5.22 |
| 4 | 92.00-91.25 | 3970 | 6500 | 26.30 | 27.20 | 26.80 | -11.43 | 0 | +66°L | 19 | 6.02 |
| 5 | 94.13-93.63 | 2624 | 6600 | 27.15 | 27.33 | 26.90 | -13.55 | 0 | +81°L | 21 | 7.49 |
| 6 | 95.30-95.10 | 988 | 3400 | 33.55 | 33.95 | 33.75 | -20.80 | 0 | +61°L | 14 | 7.90 |
| 7 | 101.50-101.00 | 2620 | 24000 | 11.60 | 10.70 | 11.20 | +12.25 | 0 | +89°L | 14 | 5.38 |
| 8 | 105.74-105.34 | 2088 | 19150 | 21.90 | 21.90 | 21.90 | +2.79 | 0 | +72°L | 16 | 6.51 |
| 9 | 104.40-104.10 | 1580 | 24500 | 17.30 | 16.30 | 16.80 | +13.35 | 0 | -86°L | 15 | 6.13 |
| 10 | 105.72-105.42 | 1640 | 12500 | 27.30 | 26.50 | 27.30 | +2.90 | 0 | -84°L | 10 | 5.63 |
| 11 | 111.16-110.86 | 1600 | 35800 | 5.10 | 5.10 | 5.10 | +19.80 | 0 | -78°L | 13 | 6.60 |
| 12 | 116.00-115.50 | 2240 | 17200 | 17.10 | 17.00 | 17.10 | +2.24 | 0 | -84°L | 13 | 6.08 |

* See page 35, Appendix A.


TRAIN RESISTANCE
TEST S 1017
NOTES:
○ INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE 9.61 TONS.
TRAIN RESISTANCE LBS. PER TON
SPEED M. P. H.
4
6
8
10
12
14
16
20
24
28
32
36

TEST NO. S - 1018

From Gilman to Champaign - May 2, 1908

Freight train No. Extra 920 - South. Engine No. 920.

300 Pound Spring. 1/2 square inch Piston Area.

Total weight behind measuring draw-bar, 1353 tons, including No.17.

Train length, 2130 ft. Number of Cars 49, Empties 33 Loads 15.

Weight per axle, 6.35 tons.

Kind of Cars: 28 Box 8 Flat 8 Tank 3 Gondola 1 Caboose

1 Test 2 I. C. Locomotives (#423 & #732).

Weather: Clear. Temperature 40° F., at start. 45° F., at end of test.

## T E S T N O. S - 1018

### METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location: Mile Post Number | Total Draw-bar Pull: Pounds P | Acceleration: Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 5 | 93.94 | 13300 | 0 | +8.92 | 0 | +83°R | 15 | 16.0 | 6.47 |
| 6 | 94.59 | 14600 | 0 | +10.90 | 0 | +72°R | 11 | 14.7 | 6.67 |
| 7 | 96.34 | 20600 | -0.0018 | +26.50 | 0 | +54°R | 7 | 10.6 | 5.32 |
| 8 | 97.29 | 14750 | -0.0042 | +9.30 | 0 | +43°R | 13 | 17.95 | 7.78 |
| 9 | 98.68 | 22000 | -0.0048 | +28.80 | 0 | +60°R | 8 | 9.45 | 5.82 |
| 10 | 100.15 | 18500 | -0.0025 | +22.00 | 0 | +83°R | 14 | 13.1 | 5.57 |
| 11 | 102.00 | 9470 | +0.0159 | -8.90 | 0 | +75°R | 13 | 24.8 | 8.83 |
| 12 | 104.43 | 4750 | -0.0263 | -20.10 | 0 | +11°R | 22 | 30.2 | 8.59 |
| 13 | 105.34 | 5000 | -0.0046 | -10.15 | 0 | +63°R | 14 | 29.3 | 8.00 |
| 14 | 106.25 | 7000 | -0.0419 | +7.44 | 0 | +45°R | 11 | 26.3 | 6.40 |
| 15 | 106.40 | 8300 | -0.0645 | +13.90 | 0 | +50°R | 11 | 25.7 | 7.12 |
| 16 | 106.53 | 8550 | -0.0644 | +15.40 | 0 | -54°R | 10 | 24.2 | 6.72 |
| 17 | 106.64 | 9350 | -0.0596 | +15.60 | 0 | +59°R | 11 | 23.15 | 6.77 |
| 18 | 106.71 | 10250 | -0.0419 | +14.37 | 0 | -61°R | 10 | 22.5 | 6.18 |
| 19 | 106.90 | 10000 | -0.0419 | +12.15 | 0 | +46°R | 11 | 21.0 | 6.85 |
| 20 | 107.07 | 11000 | -0.0419 | +14.38 | 0 | +45°R | 9 | 19.7 | 6.74 |
| 21 | 107.47 | 12000 | -0.0419 | +17.10 | 0 | +47°R | 8 | 17.0 | 6.44 |
| 22 | 108.23 | 16000 | 0 | +16.10 | 0 | +45°R | 7 | 13.8 | 5.72 |
| 23 | 109.17 | 8750 | 0 | -2.72 | 0 | +46°R | 9 | 21.5 | 7.50 |
| 26 | 115.94 | 9200 | 0 | -5.70 | 0 | +37°R | 12 | 23.2 | 7.00 |

*See page 35, Appendix A.

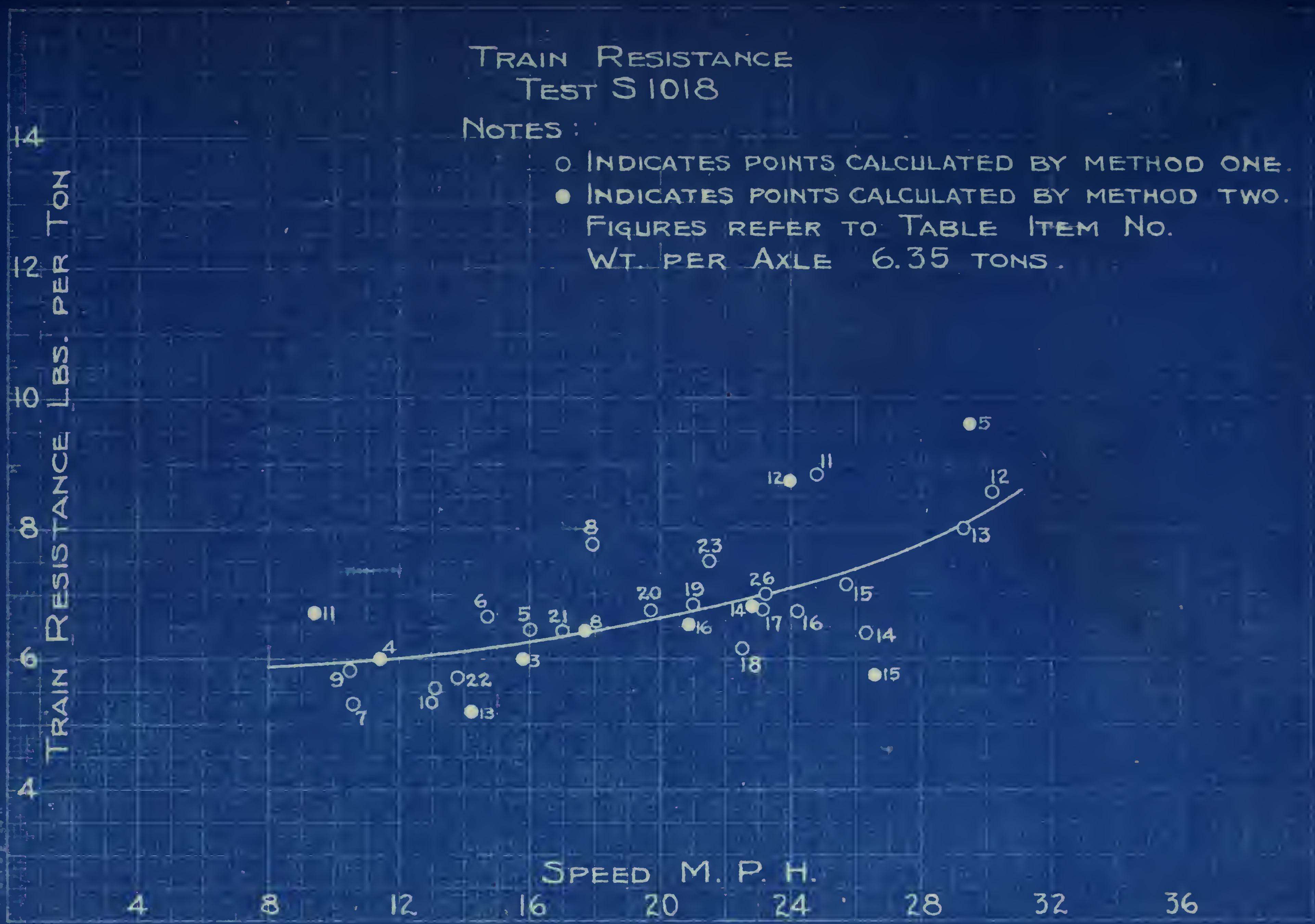
TEST NO. S - 1018

METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS 1000 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. V1 | Speed at Exit M.P.H. V2 | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up -Down | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 3 | 92.00-92.51 | 2675 | 12800 | 16.2 | 15.2 | 15.8 | -11.20 | 0 | +80°R | 12 | 6.00 |
| 4 | 96.22-96.74 | 2770 | 21250 | 11.3 | 11.3 | 11.4 | +25.50 | 0 | +54°R | 7 | 6.02 |
| 5 | 104.43-105.34 | 4800 | 5100 | 29.7 | 29.2 | 29.5 | -14.30 | 0 | +63°R | 14 | 9.62 |
| 8 | 126.0-126.455 | 2400 | 9600 | 18.2 | 17.70 | 17.68 | +3.08 | 0 | +61°R | 12 | 6.46 |
| 9 | 83.33-84.00 | 3532 | 13700 | 16.32 | 16.8 | 16.5 | +5.85 | 0 | +62°R | 15 | 7.59 |
| 11 | 98.55-98.85 | 1588 | 22000 | 10.35 | 10.12 | 9.4 | +25.70 | 0 | +60°R | 8 | 6.72 |
| 12 | 101.70-102.00 | 1584 | 10100 | 23.41 | 24.77 | 24.0 | -11.00 | 0 | +75°R | 13 | 8.74 |
| 13 | 108.08-108.41 | 1748 | 15000 | 14.2 | 14.2 | 14.2 | +16.30 | 0 | +45°R | 7 | 5.21 |
| 14 | 106.00-107.297 | 6840 | 9300 | 28.05 | 18.23 | 22.8 | +12.50 | 0 | --- | -- | 6.82 |
| 15 | 106.00-106.53 | 2750 | 7500 | 28.05 | 24.32 | 26.6 | +7.88 | 0 | --- | -- | 7.59 |
| 16 | 106.53-107.30 | 4096 | 10500 | 24.52 | 28.23 | 20.9 | +15.10 | 0 | --- | -- | 6.52 |

*See Page 35, Appendix A


TRAIN RESISTANCE
TEST S 1018
NOTES:
○ INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WT. PER AXLE 6.35 TONS.
TRAIN RESISTANCE LBS. PER TON
SPEED M. P. H.
4
8
12
16
20
24
28
32
36
4
6
8
10
12
14

TEST NO. S - 1019

From Champaign to Mattoon - May 9, 1908.

Freight train No. Extra 760 - South. Engine No. 760.

500 Pound Spring. 1 square inch Piston Area.

Total weight behind measuring draw-bar, 1572 tons, excluding No.17.

Train length 3480 ft. Number of Cars, 89. Empties 75 Loads 14.

Weight per axle, 4.43 tons.

Kind of Cars: 28 Box 52 Coal 6 Flat 1 Refrigerator 1 Tank 1 Caboose.

Weather: Fine. Temperature 44° F., at start, 62° F., at end of test.

T E S T  N O. S - 1019

METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location: Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration: Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature C | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 6 | 141.18 | 10700 | 0 | - 3.75 | 0 | +30°L | 21 | 18.2 | 8.23 |
| 7 | 143.80 | 9000 | 0 | - 9.03 | 0 | +24°L | 27 | 20.25 | 9.14 |
| 8 | 144.90 | 11000 | 0 | -4.16 | 0 | +30°L | 21 | 18.5 | 8.58 |
| 9 | 147.30 | 7500 | 0 | -12.70 | 0 | +19°L | 30 | 24.3 | 9.61 |
| 10 | 149.80 | 11800 | 0 | -3.64 | 0 | +30°L | 21 | 18.0 | 8.89 |
| 11 | 145.98 | 9000 | +0.0289 | -14.52 | 0 | +21°L | 31 | 21.0 | 8.36 |
| 12 | 146.19 | 8700 | +0.0289 | -17.95 | 0 | +21°L | 31 | 21.75 | 9.46 |
| 13 | 146.38 | 8050 | +0.0240 | -19.50 | 0 | +34°L | 20 | 23.2 | 10.14 |
| 14 | 146.54 | 7400 | +0.0289 | -20.50 | 0 | +21°L | 31 | 23.6 | 9.62 |
| 17 | 157.125 | 16000 | 0 | +7.21 | 0 | +27°L | 17 | 11.56 | 7.44 |
| 18 | 159.82 | 15400 | 0 | +5.22 | 0 | +27°L | 17 | 12.45 | 7.82 |
| 19 | 161.44 | 9800 | 0 | -7.66 | 0 | +18°L | 32 | 20.3 | 9.13 |
| 20 | 165.93 | 13250 | 0 | +2.30 | 0 | +45°L | 15 | 14.7 | 7.54 |

* See page 35, Appendix A.

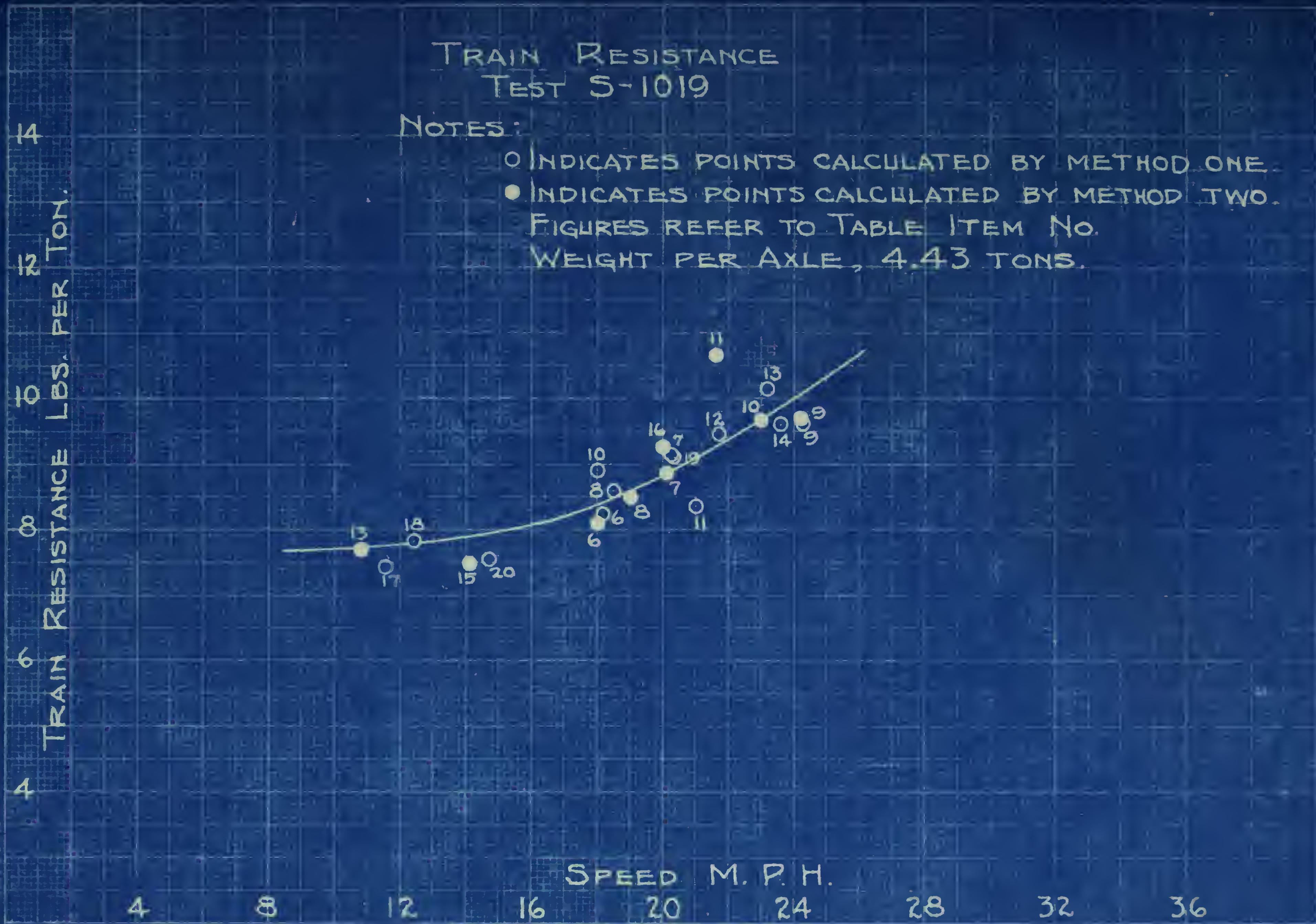
TEST NO. S - 1019

METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS 1600 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. $V_1$ | Speed at Exit M.P.H. $V_2$ | Avg. Speed M.P.H. V | Grade Ft. per mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 6 | 141.18-141.56 | 2370 | 10900 | 17.9 | 17.9 | 18.0 | -3.03 | 0 | +30° L | 21 | 8.09 |
| 7 | 143.80-144.27 | 2450 | 9200 | 20.2 | 20.0 | 20.1 | -7.33 | 0 | +24° L | 27 | 8.86 |
| 8 | 144.89-145.44 | 2890 | 10200 | 18.5 | 19.5 | 19.0 | -7.80 | 0 | +30° L | 21 | 8.49 |
| 9 | 146.98-144.47 | 2568 | 7000 | 24.25 | 24.25 | 24.25 | -13.76 | 0 | +19° L | 30 | 9.67 |
| 10 | 146.19-146.54 | 1856 | 8250 | 21.54 | 23.86 | 23.0 | -7.90 | 0 | +21° L | 31 | 9.67 |
| 11 | 145.99-146.38 | 2064 | 8850 | 20.85 | 23.18 | 21.65 | -8.90 | 0 | +21° L | 31 | 10.66 |
| 13 | 155.83-156.33 | 2640 | 18000 | 10.78 | 10.78 | 10.78 | +9.90 | 0 | +35° L | 19 | 7.70 |
| 15 | 165.66-166.16 | 2640 | 12950 | 14.0 | 14.0 | 14.1 | +2.00 | 0 | +30° L | 21 | 7.48 |
| 16 | 161.21-161.61 | 2112 | 10100 | 19.83 | 19.97 | 20.0 | -3.2 | 0 | +18° L | 32 | 9.26 |

* See page 35, Appendix A.


TRAIN RESISTANCE
TEST S-1019
NOTES:
○ INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE, 4.43 TONS.
TRAIN RESISTANCE LBS. PER TON.
SPEED M. P. H.
4
8
12
16
20
24
28
32
36
4
6
8
10
12
14

TEST NO. S - 1021

From Champaign to Paxton - May 13, 1908

Freight train No. Extra 940 - North. Engine No. 940.

300 Pound Spring. 1/2 square inch Piston Area.

Total weight behind measuring draw-bar.

(Champaign to Rantoul 2810 tons) including No. 17.
(Rantoul to Paxton 2908 tons)

Train length (Champaign to Rantoul 2310 ft)
(Rantoul to Paxton 2400 ft)

Number of Cars (Champaign to Rantoul - 61) Empties (C - R 10)
(Rantoul to Paxton - 63 ) (R - P 12)

Loads 51.

Weight per axle 11.52 tons.

Kind of Cars: 38 Coal, (C - R 11) (R - P 13) Box, 2 Tanks, 3 Flat,

5 Refrigerators, 1 Caboose, 1 Test Car.

Weather: Rainy. Temperature 66°F., at start, 70° F., at end of test.

## T E S T  N O. S - 1021

### METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location: Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 7 | 106.79 | 10500 | +0.0362 | -16.70 | 0 | +73°R | 13 | 26.6 | 6.55 |
| 8 | 105.82 | 10800 | -0.0056 | -6.60 | 0 | +79°R | 15 | 29.9 | 6.74 |
| 9 | 105.74 | 12050 | -0.0172 | -3.96 | 0 | +79°R | 15 | 29.6 | 7.26 |
| 10 | 104.65 | 18650 | -0.0490 | +15.80 | 0 | +67°R | 16 | 23.25 | 5.02 |
| 11 | 104.59 | 19000 | -0.0490 | +16.05 | 0 | +69°R | 15 | 22.80 | 5.06 |
| 12 | 104.53 | 20850 | -0.0490 | +16.30 | 0 | +68°R | 16 | 22.25 | 5.61 |
| 13 | 104.41 | 21300 | -0.0425 | +15.20 | 0 | +72°R | 15 | 21.35 | 5.57 |
| 14 | 104.32 | 21100 | -0.0425 | +14.10 | 0 | +72°R | 17 | 20.75 | 5.92 |
| 15 | 104.21 | 21300 | -0.0425 | +14.08 | 0 | +82°R | 19 | 19.85 | 5.99 |
| 16 | 104.10 | 21800 | -0.0425 | +16.90 | 0 | +72°R | 20 | 19.0 | 5.08 |
| 17 | 103.62 | 28900 | -0.0540 | +28.60 | 0 | +75°R | 18 | 13.6 | 4.30 |
| 18 | 103.50 | 30750 | -0.0530 | +29.50 | 0 | +60°R | 16 | 10.4 | 4.24 |
| 19 | 103.72 | 27750 | -0.0583 | +27.90 | 0 | +63°R | 21 | 14.7 | 5.46 |
| 20 | 105.40 | 12200 | -0.0490 | +5.94 | 0 | +80°R | 15 | 28.5 | 6.55 |
| 21 | 104.82 | 17250 | -0.0490 | +11.90 | 0 | +82°R | 18 | 24.5 | 5.94 |
| 22 | 106.84 | 10750 | +0.0362 | -17.40 | 0 | | | 26.4 | 6.90 |
| 23 | 105.95 | 11500 | +0.0156 | -13.00 | 0 | | | 29.8 | 7.41 |

*See page 35. Appendix A

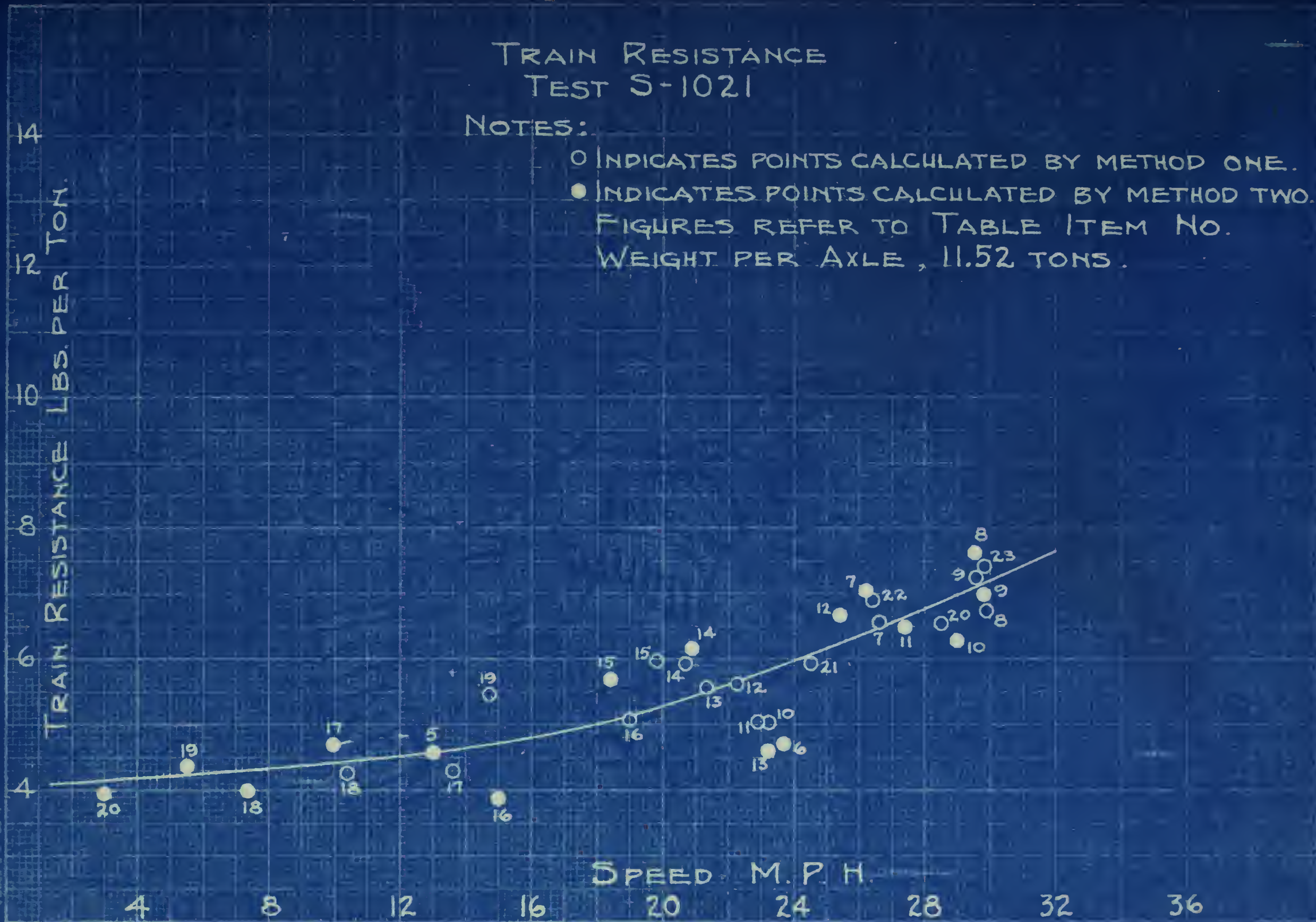
TEST NO. S - 1021

METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS (Champaign to Rantoul 1300 ft) (Rantoul to Paxton 1200 ft) FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. $V_1$ | Speed at Exit M.P.H. $V_2$ | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 7 | 107.04-106.73 | 1596 | 10850 | 25.44 | 26.92 | 26.2 | -14.00 | 0 | +74°R | 12 | 7.03 |
| 8 | 106.30-106.00 | 1588 | 11200 | 28.75 | 29.75 | 29.5 | -13.20 | 0 | +77°R | 14 | 7.63 |
| 9 | 106.00-105.70 | 1588 | 11150 | 29.75 | 29.75 | 29.8 | -6.60 | 0 | +79°R | 15 | 6.99 |
| 10 | 105.70-105.40 | 1584 | 11650 | 29.75 | 28.40 | 29.0 | +2.40 | 0 | +80°R | 15 | 6.29 |
| 11 | 105.40-105.10 | 1592 | 13700 | 28.40 | 26.43 | 27.4 | +6.07 | 0" | +80°R | 15 | 6.50 |
| 12 | 105.10-104.80 | 1584 | 16500 | 26.43 | 24.32 | 25.4 | +7.70 | 0 | +82°R | 18 | 6.66 |
| 13 | 104.80-104.49 | 1588 | 18500 | 24.32 | 22.07 | 23.2 | +13.20 | 0 | +68°R | 16 | 4.60 |
| 14 | 104.49-104.19 | 1580 | 21350 | 22.07 | 19.80 | 20.9 | +11.10 | 0 | -72°R | 16 | 6.16 |
| 15 | 104.19-103.89 | 1576 | 22300 | 19.08 | 17.00 | 18.4 | +13.50 | 0 | +72°R | 20 | 5.69 |
| 16 | 103.89-103.50 | 1600 | 26600 | 17.0 | 12.95 | 15.0 | +27.75 | 0 | +63°R | 21 | 3.87 |
| 17 | 103.50-103.33 | 868 | 32500 | 11.52 | 8.45 | 10.0 | +30.00 | 0 | | | 4.69 |
| 18 | 103.33-103.21 | 648 | 32250 | 8.45 | 6.41 | 7.4 | +30.00 | 0 | | | 3.99 |
| 19 | 103.21-103.12 | 464 | 36750 | 6.41 | 4.5 | 5.5 | +30.00 | 0 | | | 4.38 |
| 20 | 103.12-103.03 | 512 | 37600 | 4.50 | 1.64 | 3.0 | +30.00 | 0 | | | 5.94 |

* See Page 35, Appendix A


TRAIN RESISTANCE
TEST S-1021
NOTES:
O INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE, 11.52 TONS.
TRAIN RESISTANCE LBS. PER TON
SPEED M.P.H.
4
6
8
10
12
14
4
8
12
16
20
24
28
32
36

TEST NO. S - 1023

From Champaign to Paxton - May 23, 1908.

Freight train No. Extra 579 - North. Engine No. 579.

500 Pound Spring. 1 square inch Piston Area.

Total weight behind measuring draw-bar, 2243 tons, including No.17.

Train length, 2320 ft. Number of cars, 58. Empties 17 Loads 41

Weight per axle, 9.68 tons.

Kind of Cars: 30 Coal 22 Box 2 Tank 2 Refrigerators

1 Caboose 1 Test.

Weather: Clear. Temperature 62° F., at start. 74° F., at end of test.

## T E S T N O. S - 1023

### METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 5 | 114.00 | 18400 | 0 | +8.88 | 0 | +87° R | 15 | 10.2 | 4.84 |
| 8 | 106.71 | 10300 | +0.0360 | -16.00 | 0 | +82° R | 18 | 26.5 | 7.24 |
| 9 | 104.91 | 12500 | -0.0600 | +10.70 | 0 | +85° R | 17 | 23.0 | 7.19 |
| 10 | 104.48 | 17000 | -0.0500 | +16.03 | 0 | -80° R | 17 | 19.65 | 6.71 |
| 11 | 103.98 | 20600 | -0.0500 | +20.30 | 0 | +77° R | 19 | 15.00 | 6.22 |
| 12 | 104.04 | 19200 | -0.0400 | +17.80 | 0 | -88° R | 18 | 16.5 | 5.94 |
| 13 | 104.12 | 18500 | -0.0400 | +16.00 | 0 | -84° R | 20 | 17.5 | 5.97 |
| 14 | 104.67 | 14850 | -0.0675 | +15.28 | 0 | +87° R | 17 | 20.68 | 7.23 |

* See page 35, Appendix A.

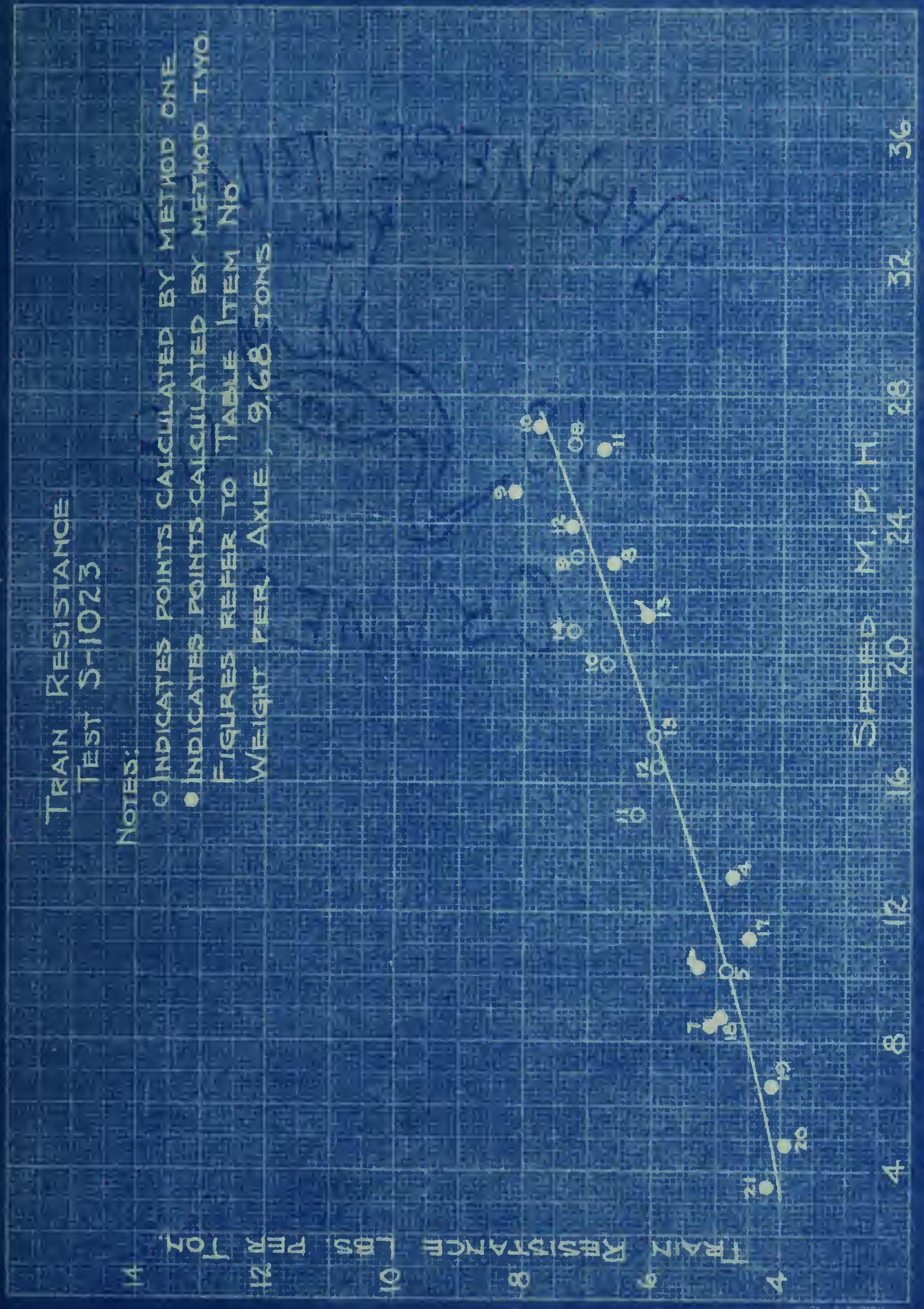
T E S T N O. S - 1023

METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS 1020 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft. S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. $V_1$ | Speed at Exit M.P.H. $V_2$ | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 4 | 116.50-116.00 | 2640 | 14700 | 13.1 | 13.1 | 13.1 | +4.81 | 0 | 90° R | 13 | 4.73 |
| 5 | 114.71-114.21 | 2640 | 18600 | 10.3 | 10.3 | 10.3 | +7.92 | 0 | +87° R | 15 | 5.30 |
| 7 | 110.88-110.38 | 2240 | 29000 | 8.5 | 8.5 | 8.5 | +20.70 | 0 | +82° R | 14 | 5.10 |
| 8 | 108.95-108.56 | 2104 | 9700 | 23.86 | 21.45 | 22.8 | +3.38 | 0 | +90° R | 17 | 6.64 |
| 9 | 107.21-106.71 | 2644 | 11250 | 23.60 | 26.43 | 25.05 | -18.15 | 0 | +82° R | 18 | 8.18 |
| 10 | 106.71-106.21 | 2616 | 10550 | 26.43 | 28.05 | 27.0 | -14.30 | 0 | +82° R | 18 | 7.78 |
| 11 | 105.47-105.17 | 1584 | 10850 | 27.27 | 25.10 | 26.3 | +8.00 | 0 | +87° R | 25 | 6.78 |
| 12 | 105.17-104.87 | 1580 | 12050 | 25.10 | 22.60 | 23.9 | +9.01 | 0 | +85° R | 17 | 7.18 |
| 13 | 104.87-104.57 | 1584 | 14450 | 22.60 | 19.65 | 21.2 | +15.30 | 0 | +87° R | 17 | 6.07 |
| 17 | 103.81-103.64 | 920 | 25650 | 11.86 | 9.28 | 11.2 | +29.30 | 0 | | | 4.48 |
| 18 | 103.64-103.50 | 716 | 28150 | 9.28 | 7.24 | 8.72 | +28.75 | 0 | | | 4.92 |
| 19 | 103.50-103.40 | 546 | 30000 | 7.24 | 5.46 | 6.66 | +31.90 | 0 | | | 4.17 |
| 20 | 103.40-103.22 | 394 | 31850 | 5.46 | 3.82 | 4.8 | +34.20 | 0 | | | 3.93 |
| 21 | 103.32-103.27 | 292 | 33200 | 3.82 | 2.59 | 3.56 | +32.90 | 0 | | | 4.21 |

* See Page 35, Appendix A.



TRAIN RESISTANCE
TEST S-1023
NOTES:
○ INDICATES POINTS CALCULATED BY METHOD ONE
● INDICATES POINTS CALCULATED BY METHOD TWO
FIGURES REFER TO TABLE, ITEM NO
WEIGHT PER AXLE, 9.68 TONS
SPEED M.P.H.
TRAIN RESISTANCE LBS PER TON
4
8
12
16
20
24
28
32
36
14
12
10
8
6
4

TEST NO. S - 1027

From Champaign to Gilman - July 2, 1908.

Freight train No. Extra 722 - North. Engine No. 722.

500 Pound Spring. 1 square inch Piston Area.

Total weight behind measuring draw-bar, 2185 tons, including No.17.

Train length, 1710 ft. Number of Cars 46, Empties 3 Loads 43.

Weight per axle, 11.86 tons.

Kind of Cars: 35 Coal 8 Box 1 Flat 1 Caboose 1 Test.

Weather: Rainy to Ludlow, then clear. Temperature 64° F., at start, 80° F., at end of test.

TEST NO. S - 1027

METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 4 | 114.49 | 16400 | 0 | +8.12 | 0 | -61°R | 8 | 15.7 | 4.42 |
| 7 | 110.51 | 25900 | 0 | +19.72 | 0 | -48°R | 8 | 9.5 | 4.37 |
| 10 | 105.91 | 6900 | 0 | -9.16 | 0 | +88°R | 13 | 34.0 | 6.63 |
| 11 | 103.00 | 29700 | -0.0054 | +27.20 | 0 | -56°R | 5 | 8.2 | 3.81 |
| 12 | 101.91 | 8100 | 0 | -6.54 | 0 | +89°R | 17 | 28.1 | 6.16 |
| 13 | 100.57 | 14400 | 0 | +4.11 | 0 | -69°R | 14 | 14.5 | 5.00 |
| 14 | 99.49 | 5300 | 0 | -9.56 | 0 | -83°R | 11 | 28.9 | 6.08 |
| 16 | 97.10 | 3750 | +0.0420 | -22.90 | 0 | -85°R | 16 | 34.5 | 6.46 |
| 17 | 86.03 | 10000 | 0 | -1.325 | 0 | -72°R | 22 | 22.3 | 5.06 |

* See page 35, Appendix A

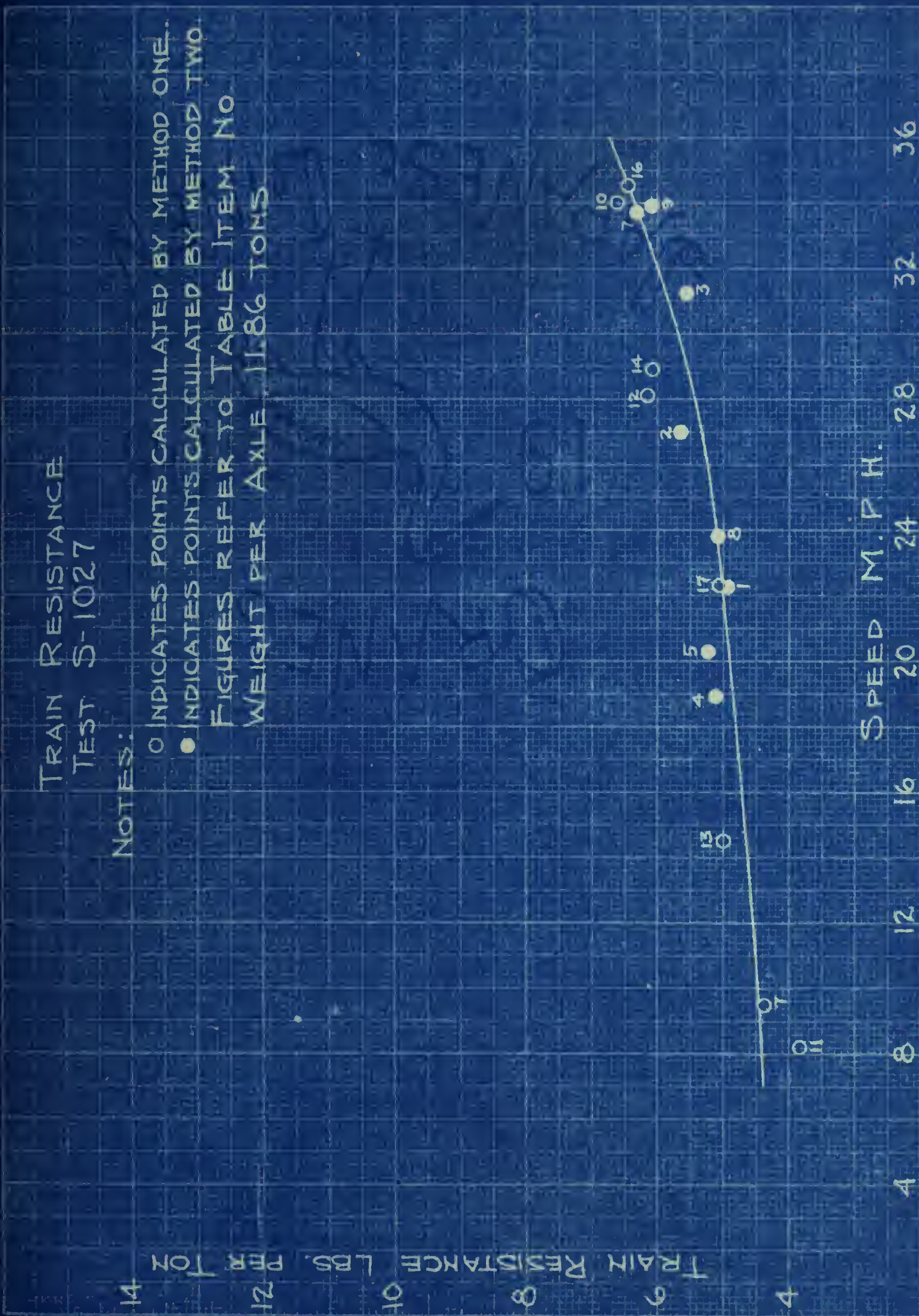
T E S T  N O. S - 1027

METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS 800 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. V1 | Speed at Exit M.P.H. V2 | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 1 | 85.40-86.30 | 2430 | 9900 | 22.3 | 22.3 | 22.25 | -1.085 | 0 | -72°R | 22. | 4.94 |
| 2 | 87.85-88.45 | 3215 | 6600 | 27.1 | 27.1 | 27.0 | -6.64 | 0 | -74°R | 15 | 5.65 |
| 3 | 89.81-90.56 | 3955 | 4500 | 31.25 | 31.25 | 31.25 | -9.22 | 0 | -80°R | 15 | 5.44 |
| 4 | 115.56-116.17 | 3280 | 12800 | 19 | 19 | 18.9 | +1.98 | 0 | -59°R | 11 | 5.11 |
| 5 | 117.10-117.93 | 4440 | 11650 | 20.2 | 20.2 | 20.3 | +0.273 | 0 | -62°R | 11 | 5.22 |
| 7 | 106.11-105.51 | 3220 | 9400 | 33.4 | 32.85 | 33.75 | -4.09 | 0 | +68°R | 13 | 6.33 |
| 8 | 98.88-98.29 | 3080 | 9050 | 22.9 | 24.7 | 23.8 | +7.55 | 0 | +70°R | 10 | 5.109 |
| 9 | 97.61-96.72 | 4720 | 4200 | 31.9 | 34.28 | 33.87 | -17.0 | 0 | +85°R | 16.4 | 6.09 |

* See page 35, Appendix A


Train Resistance
Test S-1027
Notes:
○ Indicates points calculated by method one.
● Indicates points calculated by method two.
Figures refer to Table. Item No
Weight per Axle 11.86 tons.
Speed M.P.H.
Train Resistance Lbs. per Ton
4
8
12
16
20
24
28
32
36
4
6
8
10
12
14

TEST NO. S - 1030A

From Effingham to Mattoon - July 8, 1908.

Freight train No. Extra 730 - North. Engine No. 730.

500 Pound Spring. 1 square inch Piston Area.

Total weight behind measuring draw-bar, 2035 tons, including No.17.

Train length, 1380 ft. Number of Cars, 34. Empties 2 Loads 32.

Weight per axle, 14.95 tons.

Kind of Cars: 1 Gondola 31 Coal 1 Caboose 1 Test.

Weather: Fine. Temperature 60° F., at start. 68° F., at end of test.

TEST NO. 1030A

METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature C | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 3 | 190.35 | 13200 | -0.0690 | +23.40 | 0 | | | 20.8 | 4.04 |
| 4 | 193.16 | 9050 | -0.1350 | +32.10 | 0 | | | 26.03 | 4.90 |
| 5 | 193.61 | 11000 | +0.1390 | -32.40 | 0 | | | 25.8 | 4.77 |

* See page 35, Appendix A.

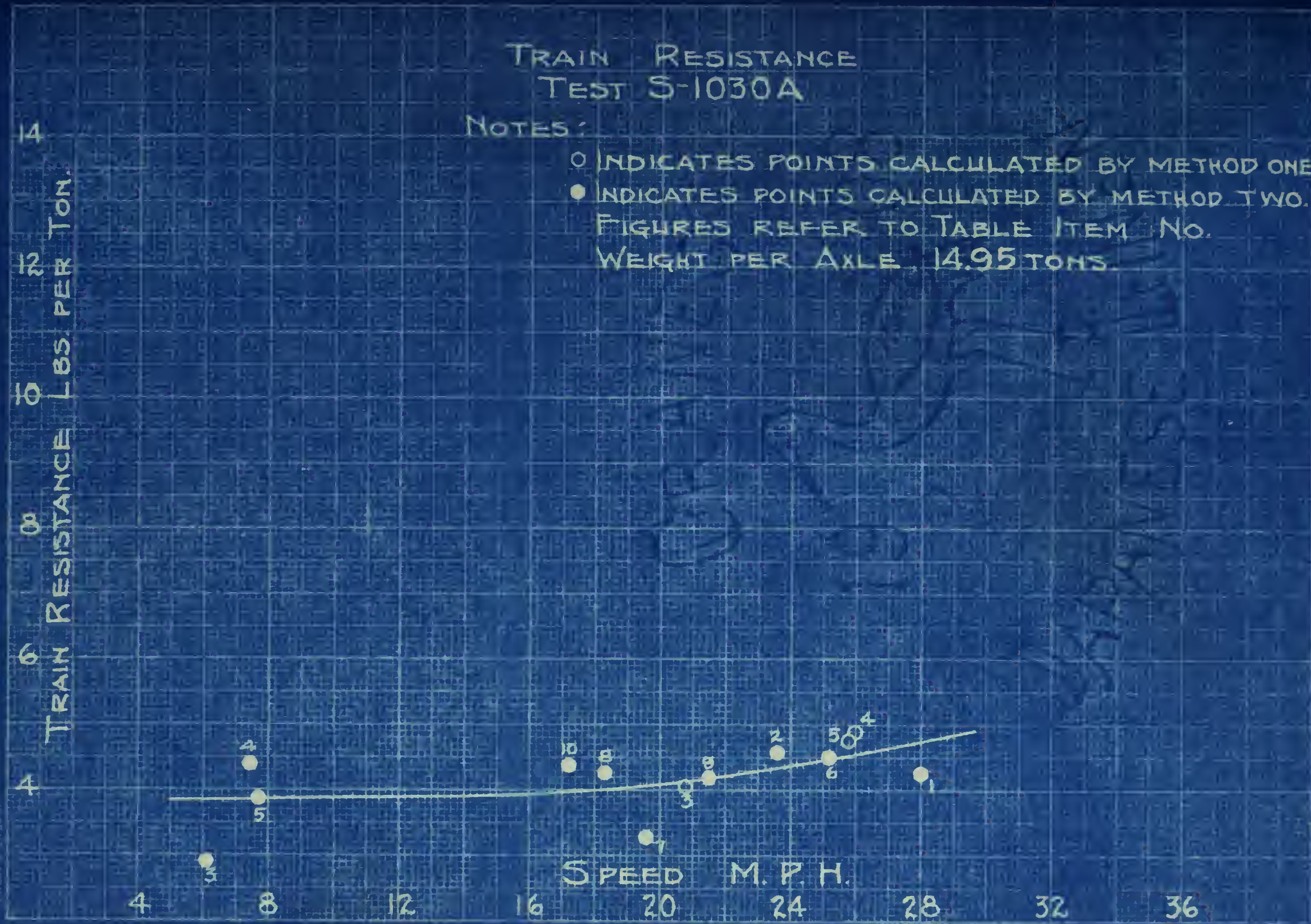
# T E S T  N O. S - 1030A.

## METHOD TWO - TRAIN RESISTANCE OVER A SECTION

### CENTER OF MASS 690 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. $V_1$ | Speed at Exit M.P.H. $V_2$ | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up -Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 1 | 174.50-173.88 | 3280 | 160 | 26.20 | 30.00 | 28.00 | -22.70 | 0 | | | 4.23 |
| 2 | 175.00-174.50 | 2600 | 5620 | 20.71 | 26.20 | 23.60 | -22.70 | 0 | | | 4.57 |
| 3 | 176.97-176.70 | 3500 | 30050 | 6.54 | 6.00 | 6.12 | +31.50 | 0 | | | 2.91 |
| 4 | 177.58-176.97 | 3212 | 30650 | 10.22 | 6.54 | 7.44 | +31.50 | 0 | | | 4.39 |
| 5 | 178.00-176.7 | 8956 | 28800 | 16.15 | 6.00 | 7.65 | +31.50 | 0 | | | 3.87 |
| 6 | 181.50-180.37 | 5144 | 12050 | 23.92 | 26.10 | 25.20 | 0 | 0 | | | 4.46 |
| 7 | 190.01-189.36 | 3452 | 12000 | 19.20 | 20.05 | 19.60 | +5.10 | 0 | | | 3.29 |
| 8 | 191.72-191.44 | 1576 | 15000 | 17.18 | 19.14 | 18.30 | 0 | 0 | | | 4.25 |
| 9 | 193.16-192.71 | 2360 | 11550 | 26.03 | 17.58 | 21.50 | +32.10 | 0 | | | 4.20 |
| 10 | 196.19-195.81 | 2140 | 14900 | 17.30 | 17.18 | 17.20 | +7.70 | 0 | | | 4.39 |

* See page 35, Appendix A.


TRAIN RESISTANCE
TEST S-1030A
NOTES:
O INDICATES POINTS CALCULATED BY METHOD ONE
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE 14.95 TONS.
TRAIN RESISTANCE LBS PER TON
SPEED M.P.H.
4
6
8
10
12
14
16
20
24
28
32
36

TEST NO. S - 1030B

From Mattoon to Champaign - July 8, 1908

Freight train No. Extra 730 - North. Engine No. 730.

500 Pound Spring. 1 square inch Piston Area.

Total weight behind measuring draw-bar, 2341 tons, including No.17.

Train length, 1650 ft. Number of Cars 41, Empties 3 Loads 38.

Weight per axle, 14.30 tons.

Kind of Cars: 1 Gondola 32 Coal 6 Box 1 Caboose 1 Test.

Weather: Fine. Temperature 68° F., at start, 72° F., at end of test.

## T E S T  N O. S - 1030B

### METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 3 | 167.46 | 7200 | 0 | -1.92 | 0 | | | 26.6 | 3.80 |
| 5 | 165.52 | 6500 | 0 | -3.20 | 0 | | | 28.9 | 3.97 |
| 6 | 164.45 | 8060 | 0 | -2.88 | 0 | $+22^\circ$R | 12 | 28.4 | 4.49 |
| 9 | 159.74 | 13800 | 0 | +5.12 | 0 | $+20^\circ$R | 7 | 15.25 | 4.00 |
| 10 | 157.80 | 18100 | +0.0356 | +5.12 | 0 | $+27^\circ$R | 6 | 12.3 | 4.23 |
| 11 | 157.75 | 17000 | +0.0356 | +1.12 | 0 | $+27^\circ$R | 6 | 13.0 | 3.50 |
| 12 | 157.57 | 16200 | +0.0356 | -0.54 | 0 | $+37^\circ$R | 6 | 14.2 | 3.93 |
| 13 | 158.06 | 23600 | +0.0457 | +5.60 | 0 | $-75^\circ$R | 4 | 8.3 | 3.70 |
| 14 | 157.94 | 21500 | +0.0457 | +2.56 | 0 | $+29^\circ$R | 5 | 10.7 | 3.96 |
| 21 | 164.15 | 7200 | +0.0700 | -21.10 | 0 | | | 28.5 | 4.48 |

* See page 35, Appendix A

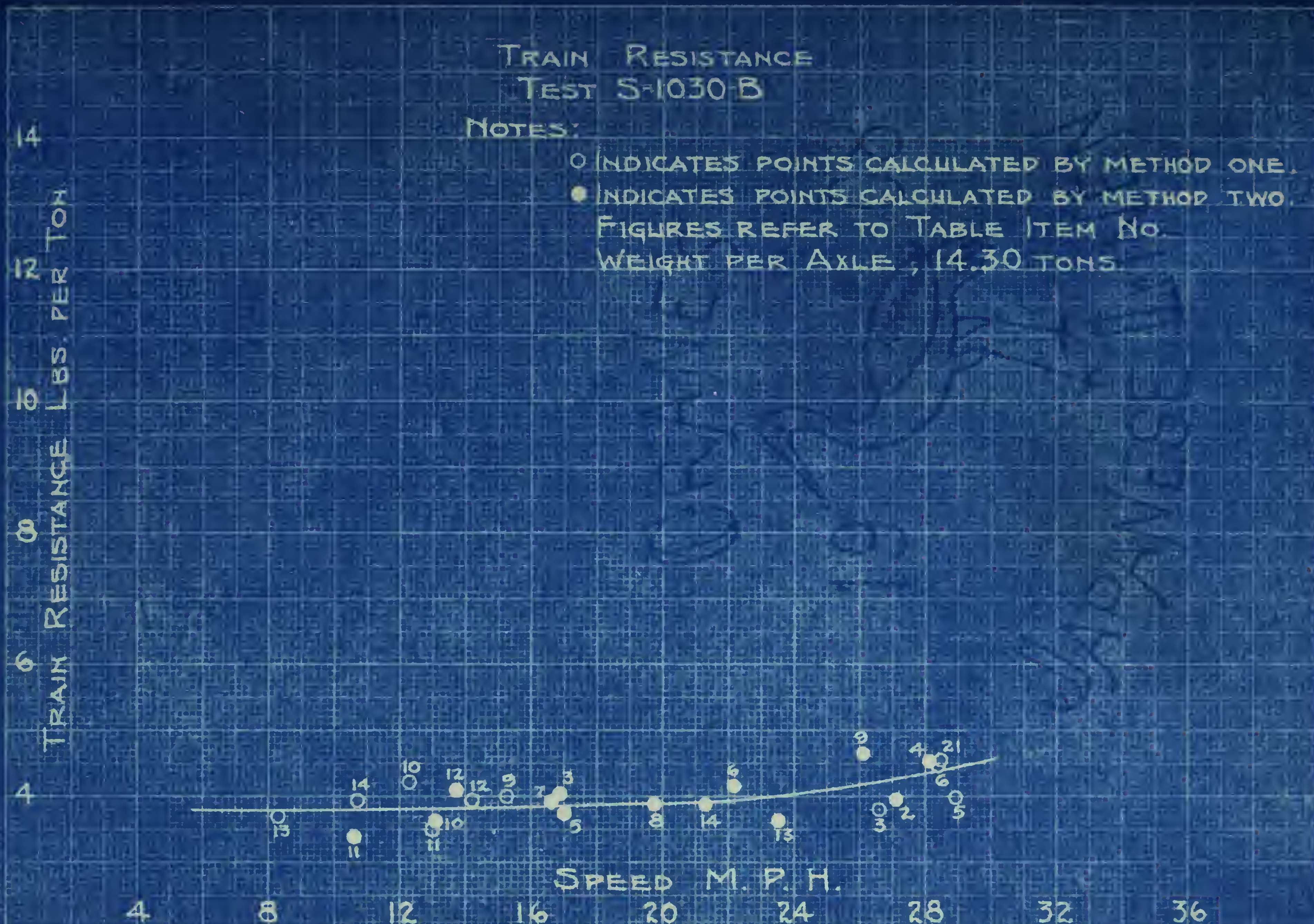
T E S T  N O. S - 1030B

METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS 900 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. $V_1$ | Speed at Exit M.P.H. V2 | Avg. Speed M.P.H. V | Grade: Ft. per Mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 1 | 166.62-167.06 | 2315 | 8000 | 25.80 | 25.80 | 25.5 | -2.12 | 0 | | | 4.22 |
| 2 | 164.45-164.95 | 3164 | 7350 | 27.40 | 27.00 | 27.15 | -0.84 | 0 | | | 3.93 |
| 3 | 158.72-159.25 | 2815 | 2500 | 17.30 | 17.30 | 16.9 | -7.82 | 0 | +66°R | 4 | 4.02 |
| 4 | 155.44-154.81 | 3300 | 7550 | 27.10 | 28.90 | 28.1 | -8.96 | 0 | +20°R | 12 | 4.52 |
| 5 | 152.25-152.88 | 3270 | 14200 | 17.50 | 17.50 | 17.0 | +6.14 | 0 | | | 3.73 |
| 6 | 149.04-148.20 | 4396 | 11800 | 21.40 | 23.00 | 22.2 | -0.66 | 0 | | | 4.18 |
| 7 | 143.32-143.92 | 3150 | 14000 | 16.30 | 16.30 | 16.6 | +5.48 | 0 | | | 3.91 |
| 8 | 140.49-141.23 | 3912 | 11950 | 19.63 | 19.25 | 19.75 | +3.77 | 0 | | | 3.93 |
| 9 | 132.65-131.68 | 5084 | 8500 | 26.75 | 25.26 | 26.05 | 0 | 0 | | | 4.68 |
| 10 | 145.06-144.48 | 3068 | 16950 | 12.47 | 13.63 | 13.1 | +7.65 | 0 | | | 3.65 |
| 11 | 158.06-157.80 | 1400 | 20850 | 8.46 | 12.55 | 10.6 | +3.40 | 0 | | | 3.41 |
| 12 | 157.80-157.57 | 1200 | 17500 | 12.55 | 14.58 | 13.7 | +0.66 | 0 | | | 4.08 |
| 13 | 162.33-161.87 | 2416 | 8730 | 23.70 | 24.40 | 23.5 | -4.36 | 0 | +19°R | 9 | 3.63 |
| 14 | 149.65-148.97 | 3280 | 12400 | 21.53 | 21.30 | 21.3 | +4.20 | 0 | | | 3.91 |

* See page 35, Appendix A.


TRAIN RESISTANCE
TEST S-1030-B
NOTES:
○ INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE, 14.30 TONS.
TRAIN RESISTANCE LBS. PER TON
14
12
10
8
6
4
SPEED M.P.H.
4
8
12
16
20
24
28
32
36

TEST NO. S - 1031

From Champaign to Dorans - July 22, 1908.

Freight train No. Extra 753 - South. Engine No. 753.

500 Pound Spring. 1 square inch Piston Area.

Total weight behind measuring draw-bar, 747 tons, excluding No.17.

Train length, 1425 ft. Number of Cars, 36. Empties 30 Loads 6.

Weight per axle, 5.18 tons.

Kind of cars: 33 Box 1 Flat 1 Coal 1 Caboose.

Weather: Fine. Temperature 70° F., at start, 82° F., at end of test.

T E S T  N O. S - 1031

METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1<br>Item No | 2<br>Location: Mile Post Number | 3<br>Total Draw-bar Pull Pounds<br>P | 4<br>Acceleration: Miles per Hour per Second<br>A | 5<br>Grade Ft. per Mile + Up - Down<br>G | 6<br>Curvature | 7*<br>Wind Direction | 8<br>Wind Velocity M.P.H. | 9<br>Speed of Train M.P.H. | 10<br>Net Train Resistance Lbs. per Ton<br>R |
|---|---|---|---|---|---|---|---|---|---|
| 4 | 142.06 | 4700 | -0.0204 | -1.50 | 0 | +0° | 5 | 26.0 | 7.25 |
| 6 | 147.10 | 2600 | 0 | -13.84 | 0 | +0° | 7 | 34.5 | 8.73 |
| 10 | 159.81 | 4200 | 0 | -3.01 | 0 | +0° | 6 | 26.0 | 6.76 |
| 13 | 163.09 | 4400 | 0 | -1.89 | 0 | +0° | 6 | 27.5 | 6.60 |
| 19 | 166.83 | 7900 | 0 | +10.20 | 0 | +0° | 2 | 21.75 | 6.70 |
| 20 | 164.40 | 12400 | +0.0275 | +21.80 | 0 | | | 15.0 | 5.68 |
| 21 | 164.75 | 9650 | +0.0550 | +1.50 | 0 | | | 18.5 | 6.95 |

* See page 35, Appendix A.

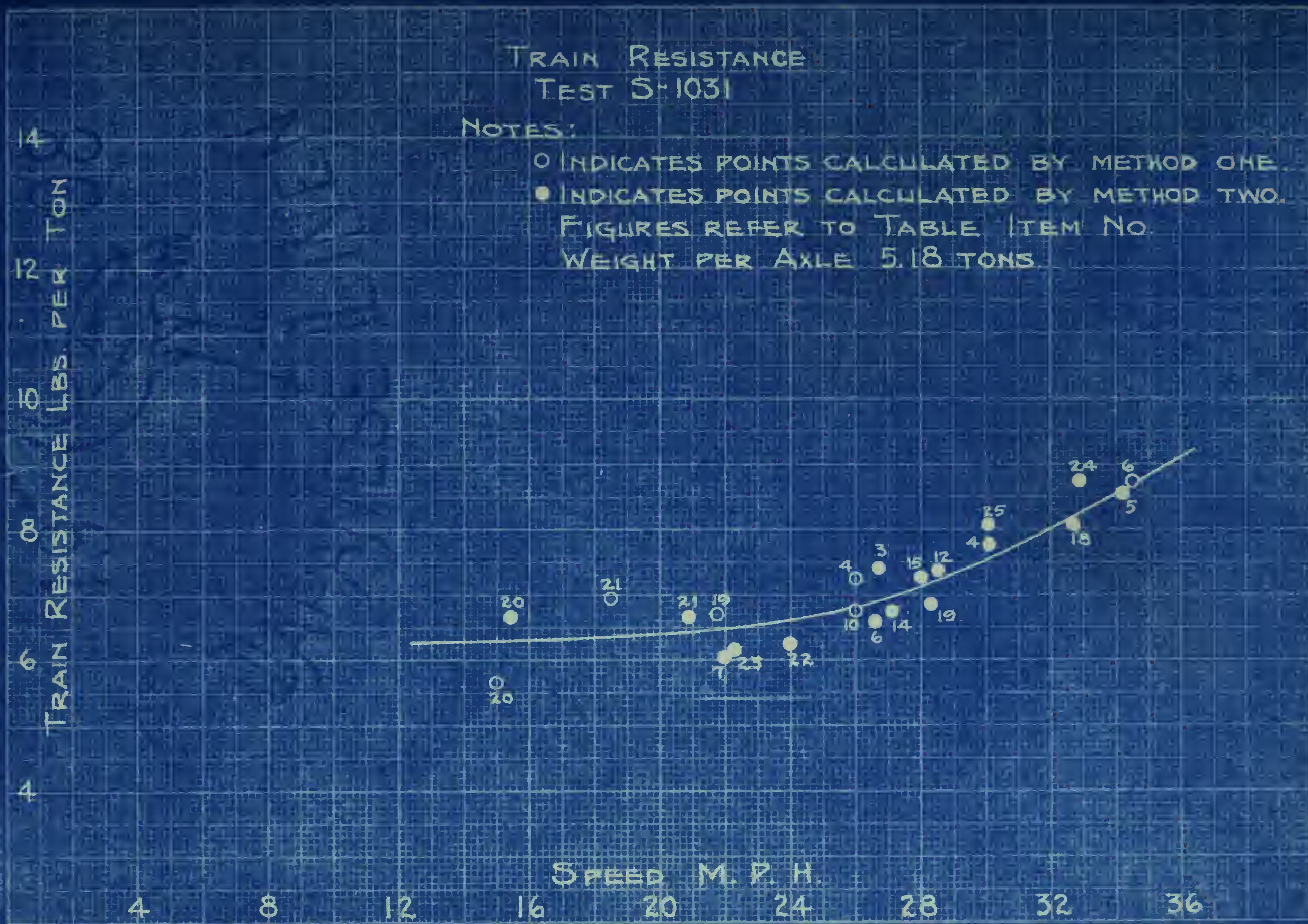
## T E S T  N O . S - 1031

### METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS 1000 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. $V_1$ | Speed at Exit M.P.H. $V_2$ | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 3 | 139.57-140.36 | 4180 | 4350 | 26.7 | 26.7 | 26.7 | -4.13 | 0 | -0° | 5 | 7.40 |
| 4 | 143.9- 144.25 | 4460 | 3900 | 29.75 | 29.75 | 30.1 | -6.81 | 0 | -0° | 5 | 7.76 |
| 5 | 146.68-147.51 | 4405 | 2500 | 33.90 | 33.90 | 34.2 | -13.65 | 0 | -0° | 7 | 8.53 |
| 6 | 151.94-152.77 | 4390 | 4950 | 26.60 | 26.60 | 26.6 | +0.18 | 0 | -0° | 4 | 6.56 |
| 7 | 155.70-156.45 | 4016 | 7100 | $V_1$ = | $V_2$ | 22.0 | +9.60 | 0 | | | 6.01 |
| 12 | 149.00-149.52 | 2760 | 4650 | 28.35 | 27.77 | 28.5 | -0.77 | 0 | | | 7.36 |
| 14 | 153.88-154.74 | 4568 | 4380 | 27.61 | 25.61 | 27.1 | +2.14 | 0 | | | 6.72 |
| 15 | 160.31-160.78 | 2468 | 4450 | 25.95 | 28.93 | 28.0 | -16.15 | 0 | | | 7.24 |
| 18 | 147.51-148.35 | 4412 | 2900 | 33.53 | 31.36 | 32.7 | -5.04 | 0 | | | 8.07 |
| 19 | 153.20-153.87 | 3528 | 4470 | $V_1$ = | $V_2$ | 28.3 | -2.25 | 0 | | | 6.85 |
| 20 | 164.40-164.74 | 1812 | 11800 | 15.00 | 18.00 | 15.4 | +13.70 | 0 | | | 6.69 |
| 21 | 164.74-165.50 | 3980 | 7700 | 18.00 | 22.75 | 20.9 | +0.40 | 0 | | | 6.65 |
| 22 | 159.63-159.16 | 2464 | 5500 | 24.80 | 23.65 | 24.0 | +7.30 | 0 | | | 6.22 |
| 23 | 157.40-158.36 | 5064 | 5450 | 22.60 | 23.85 | 22.3 | +0.94 | 0 | | | 6.11 |
| 24 | 146.17-146.68 | 2652 | 3000 | 31.90 | 33.50 | 32.9 | -19.90 | 0 | | | 8.74 |
| 25 | 161.24-161.62 | 2014 | 4100 | $V_1$ = | $V_2$ | 30.5 | -6.84 | 0 | | | 8.09 |

* See page 35, Appendix A.



TRAIN RESISTANCE
TEST S-1031
NOTES:
○ INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE 5.18 TONS
TRAIN RESISTANCE LBS. PER TON
SPEED M. P. H.
4
6
8
10
12
14
16
20
24
28
32
36

TEST NO. S - 1033

From Champaign to Gilman - September 26, 1908.

Freight train No. Extra 722 - North. Engine No. 722.

500 Pound Spring. 1 square inch Piston Area.

Total weight behind measuring draw-bar, 2275 tons, including No.17.

Train length, 1710 ft. Number of Cars, 44. Empties 2 Loads 42.

Weight per axle, 12.93 tons.

Kind of Cars: All Coal.

Weather: Fine. Temperature 66° F., at start, 82° F., at end of test.

T E S T N O. S - 1033

METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 9 | 111.08 | 26050 | 0 | +20.20 | 0 | +0° | 5 | 8.15 | 3.79 |
| 10 | 110.72 | 25150 | 0 | +19.45 | 0 | +0° | 5 | 9.75 | 3.68 |
| 12 | 104.13 | 23900 | 0 | +16.98 | 0 | -7°R | 7 | 12.00 | 4.07 |
| 13 | 98.18 | 6000 | +0.1066 | -31.50 | 0 | +3°L | 12 | 29.35 | 4.26 |
| 16 | 95.36 | 2700 | 0 | -18.50 | 0 | -5°R | 19 | 43.50 | 8.21 |
| 17 | 93.63 | 2700 | 0 | -9.88 | 0 | -5°R | 12 | 40.00 | 4.93 |
| 18 | 90.42 | 3850 | 0 | -10.49 | 0 | -3°L | 17 | 39.40 | 5.67 |
| 20 | 85.88 | 6450 | 0 | -4.02 | 0 | -2°L | 16 | 31.75 | 4.35 |
| 21 | 83.40 | 6800 | 0 | -3.40 | 0 | +3°L | 15 | 31.75 | 4.28 |

* See page 35. Appendix A

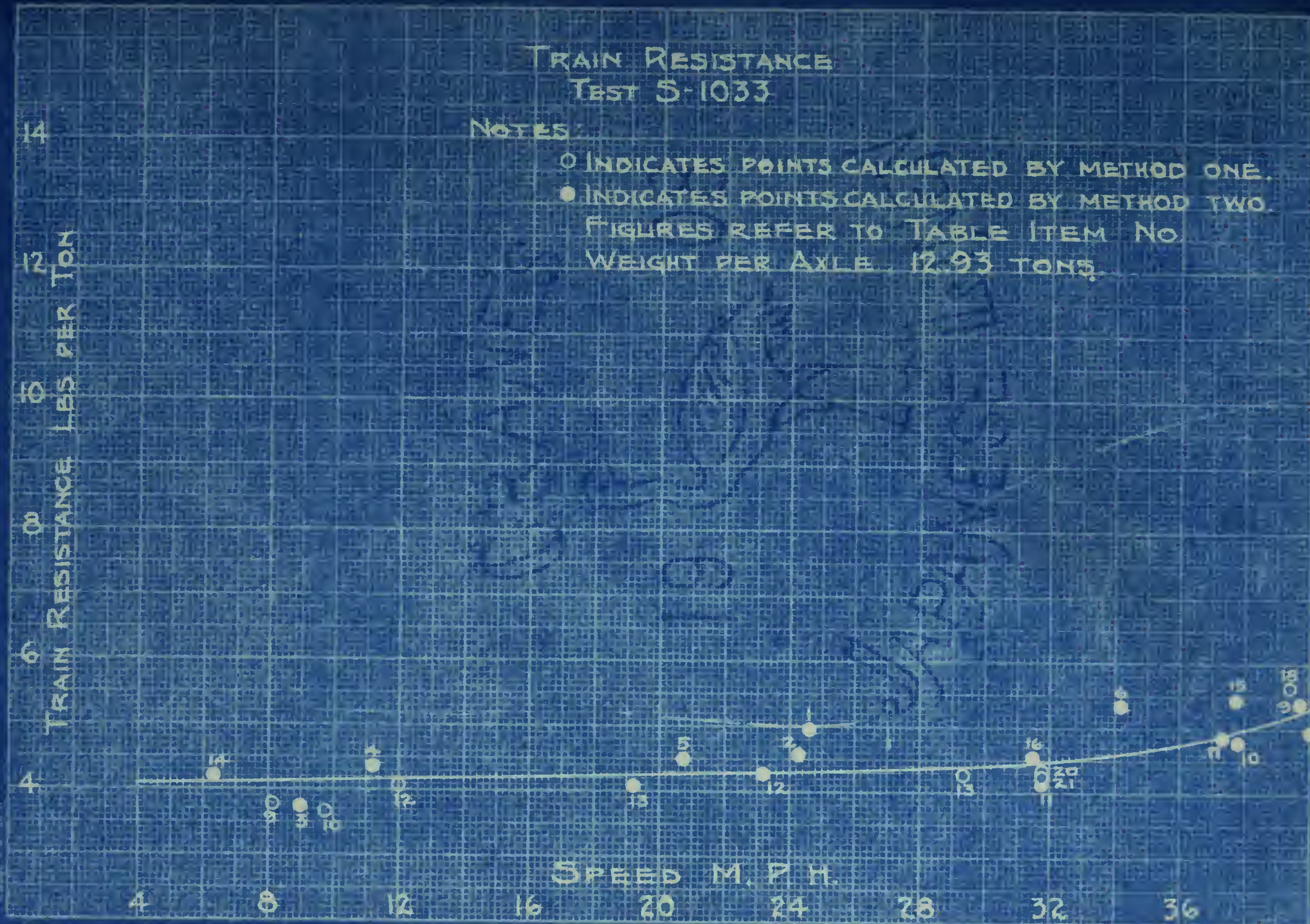
TEST NO. - 1033

METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS 850 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. V1 | Speed at Exit M.P.H. V2 | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 2 | 118.27-117.94 | 5688 | 11300 | 23.60 | 24.10 | 24.25 | +0.28 | 0 | +15°R | 6 | 4.57 |
| 3 | 111.296-110.60 | 3684 | 25900 | 8.98 | 8.98 | 8.98 | +20.20 | 0 | +0° | 5 | 3.72 |
| 4 | 104.91-103.91 | 5260 | 24000 | 11.21 | 11.21 | 11.21 | +16.30 | 0 | +7°R | 7 | 4.37 |
| 5 | 101.66-100.97 | 3660 | 12400 | 22.85 | 18.75 | 20.79 | +10.96 | 0 | +10°R | 14 | 4.50 |
| 6 | 98.18-97.14 | 5512 | 5000 | 29.20 | 37.25 | 34.17 | -25.87 | 0 | +5°L | 14 | 5.33 |
| 7 | 94.07-93.24 | 4400 | 3200 | 40.00 | 40.00 | 40.00 | -9.24 | 0 | +5°R | 12 | 4.91 |
| 8 | 96.25-95.58 | 3556 | 3200 | 37.85 | 42.10 | 40.40 | -28.80 | 0 | +3°L | 22 | 5.78 |
| 9 | 90.66-90.00 | 3492 | 4150 | 38.95 | 39.85 | 39.68 | -10.43 | 0 | +3°L | 17 | 4.38 |
| 10 | 89.24-88.76 | 2504 | 4950 | 38.30 | 37.40 | 37.94 | -1.90 | 0 | +7°L | 9 | 4.77 |
| 11 | 83.80-83.40 | 2096 | 6600 | 31.25 | 31.58 | 31.75 | -5.04 | 0 | +3°R | 14 | 4.19 |
| 12 | 116.00-115.36 | 3400 | 11800 | 23.00 | 22.40 | 23.20 | +3.99 | 0 | | | 4.23 |
| 13 | 114.67-114.27 | 2108 | 14800 | 19.50 | 18.85 | 19.20 | +8.55 | 0 | | | 4.07 |
| 14 | 103.91-103.41 | 2600 | 29900 | 10.72 | 5.81 | 6.33 | +29.20 | 0 | | | 4.20 |
| 15 | 97.14-96.25 | 4700 | 4200 | 37.50 | 38.00 | 37.70 | -10.80 | 0 | | | 5.40 |
| 16 | 83.80-83.05 | 3930 | 2900 | 32.05 | 31.10 | 31.5 | -5.78 | 0 | | | 4.53 |
| 17 | 88.77-88.00 | 4076 | 5200 | 37.53 | 37.05 | 37.3 | -5.12 | 0 | | | 4.84 |

* See page 35, Appendix A.


TRAIN RESISTANCE
TEST S-1033
NOTES
○ INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE 12.93 TONS.
TRAIN RESISTANCE LBS PER TON
SPEED M.P.H.
4
6
8
10
12
14
4
8
12
16
20
24
28
32
36

TEST NO. S - 1034

From Champaign to Mattoon - October 3, 1908.

Freight train No. Extra 755 - South. Engine No. 755.

500 Pound Spring. 1 square inch Piston Area.

Total weight behind measuring draw-bar, 1259 tons, excluding No.17.

Train length, 3015 ft. Number of Cars, 76. Empties 76 Loads 0.

Weight per axle, 4.14 tons.

Kind of Cars: 2 Gondola 74 Coal.

Weather: Fine. Temperature 42°F., at start. 60° F., at end of test.

TEST NO. S - 1034

METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 5 | 143.80 | 10000 | 0 | -9.64 | 0 | -56°L | 5 | 16.50 | 11.59 |
| 6 | 146.89 | 7900 | 0 | -15.94 | 0 | -82°L | 5 | 20.50 | 12.28 |
| 7 | 149.30 | 11800 | 0 | -0.84 | 0 | -56°L | 4 | 14.70 | 9.70 |
| 8 | 153.44 | 10300 | 0 | -5.25 | 0 | -79°L | 2 | 16.10 | 10.17 |
| 9 | 156.21 | 16440 | 0 | +9.52 | 0 | -30°L | 3 | 10.25 | 9.45 |
| 10 | 159.72 | 14400 | 0 | +5.52 | 0 | +85°L | 1 | 12.25 | 9.35 |
| 11 | 161.04 | 9150 | 0 | -12.20 | 0 | -0° | 0.8 | 18.25 | 11.49 |
| 12 | 165.81 | 13000 | 0 | +1.40 | 0 | -51°L | 5 | 14.5 | 9.76 |
| 13 | 166.80 | 15550 | 0 | +9.81 | 0 | -75°L | 3 | 12.25 | 8.62 |
| 14 | 168.45 | 17600 | 0 | +15.75 | 0 | -62°L | 3 | 7.90 | 8.00 |
| 15 | 167.93 | 12500 | 0 | +3.41 | 0 | -90°L | 5 | 11.6 | 8.65 |

* See page 35. Appendix A.

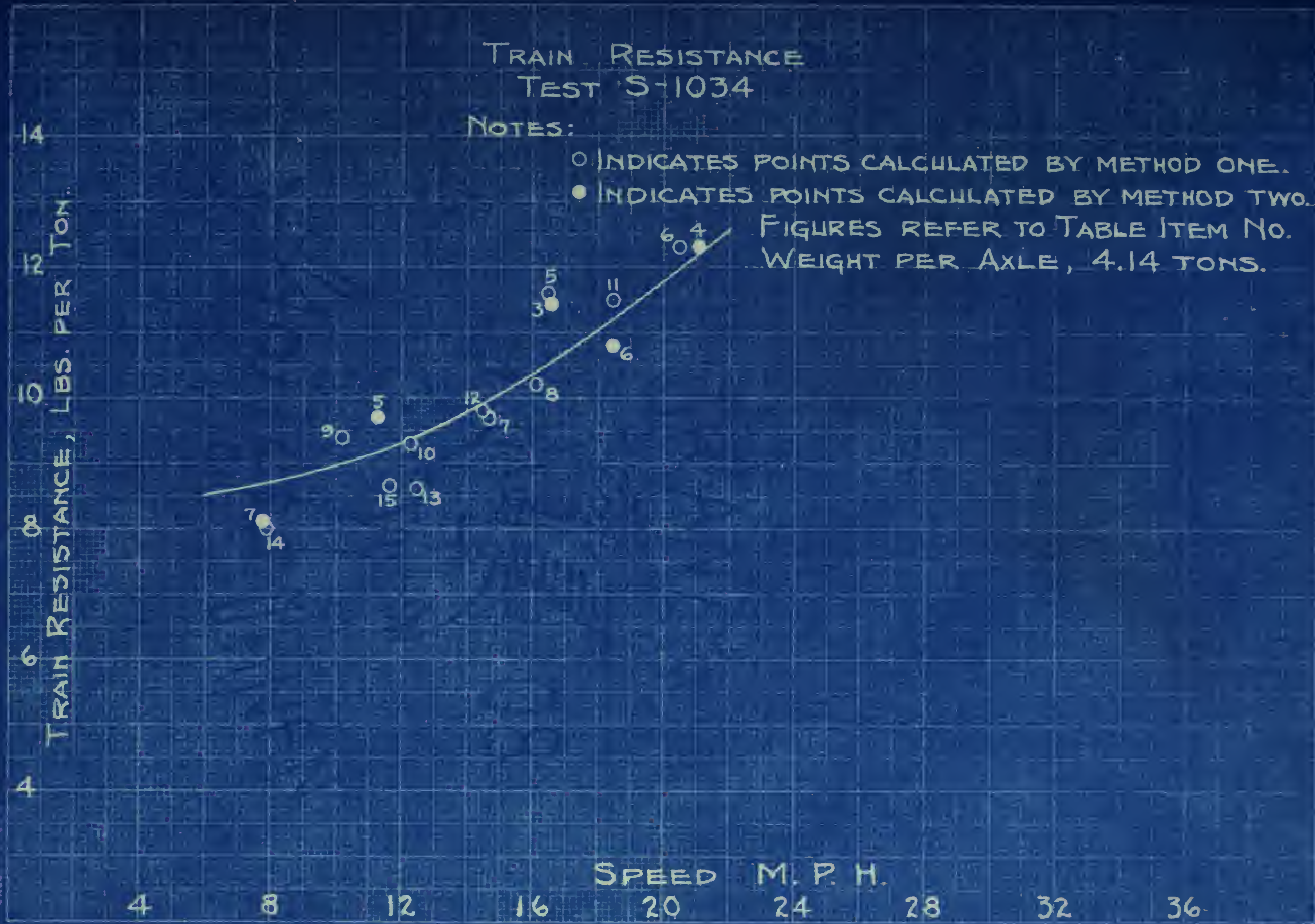
TEST NO. S - 1034

METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS 1500 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. V1 | Speed at Exit M.P.H. V2 | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 3 | 142.97-143.80 | 4373 | 10700 | 15.6 | 16.5 | 16.56 | -9.48 | 0 | -56°L | 5 | 11.45 |
| 4 | 146.40-147.54 | 6027 | 7800 | 21.0 | 21.0 | 21.1 | -16.12 | 0 | -82°L | 5 | 12.30 |
| 5 | 154.78-155.70 | 4878 | 16000 | 11.25 | 11.25 | 11.27 | +7.96 | 0 | -44°L | 5 | 9.70 |
| 6 | 160.77-161.53 | 4058 | 9100 | 17.5 | 17.5 | 18.44 | -9.375 | 0 | +84°L | 4 | 10.78 |
| 7 | 168.22-168.74 | 2744 | 18000 | 7.25 | 7.9 | 7.8 | +15.57 | 0 | -62°L | 3 | 8.12 |

* See page 35, Appendix A.


TRAIN RESISTANCE
TEST S-1034
NOTES:
○ INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE, 4.14 TONS.
TRAIN RESISTANCE, LBS. PER TON
SPEED M. P. H.
4
6
8
10
12
14
4
8
12
16
20
24
28
32
36

TEST NO. S - 1036

From Champaign to Gilman - October 10, 1908.

Freight train No. Extra 669 - North. Engine No. 669.

500 Pound Spring. 1 square inch Piston Area.

Total weight behind measuring draw-bar, 1961 tons, including No. 17.

Train length, 2010 ft. Number of Cars, 52. Empties 8 Loads 44.

Weight per axle, 9.43 tons.

Kind of Cars: 1 Flat 13 Coal 33 Box 3 Refrigerator 1 Caboose 1 Test.

Weather: Fine. Temperature 40° F., at start. 62° F., at end of test.

T E S T  N O. S - 1036

METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location: Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration: Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 6 | 111.03 | 24350 | 0 | +20.30 | 0 | -13°R | 4.5 | 9.14 | 4.71 |
| 7 | 103.06 | 30450 | 0 | +30.10 | 0 | -42°R | 3 | 5.73 | 4.12 |
| 8 | 95.32 | 3300 | 0 | -17.60 | 0 | +72°R | 11 | 36.65 | 8.35 |
| 9 | 93.75 | 3200 | 0 | -11.55 | 0 | +73°R | 8 | 31.50 | 6.01 |
| 10 | 92.16 | 1800 | 0 | -11.80 | 0 | +80°R | 6.5 | 29.15 | 5.39 |
| 11 | 90.02 | 5500 | 0 | -8.90 | 0 | +56°R | 7 | 29.50 | 6.17 |
| 12 | 86.10 | 8750 | 0 | -0.50 | 0 | +23°R | 3 | 21.60 | 4.65 |
| 13 | 83.51 | 7400 | 0 | -4.70 | 0 | +15°R | 5 | 24.75 | 5.55 |
| 14 | 81.38 | 5800 | 0 | -5.00 | 0 | +37°R | 4 | 22.50 | 4.65 |
| 15 | 104.14 | 14800 | -0.0440 | +16.03 | 0 | -64°R | 5 | 18.14 | 5.65 |
| 16 | 103.67 | 20150 | -0.0620 | +28.90 | 0 | -40°R | 9 | 12.90 | 5.20 |
| 19 | 111.20 | 23900 | -0.0260 | +24.96 | 0 | -12°R | 4 | 9.90 | 5.19 |
| 21 | 117.18 | 11800 | 0 | +0.79 | 0 | -52°R | 4 | 16.23 | 6.32 |
| 23 | 114.26 | 15100 | -0.0070 | +8.93 | 0 | -58°R | 5 | 12.54 | 4.99 |
| 26 | 103.62 | 23450 | -0.0440 | +29.16 | 0 | -33°R | 10 | 10.90 | 5.07 |

*See page 35, Appendix A.

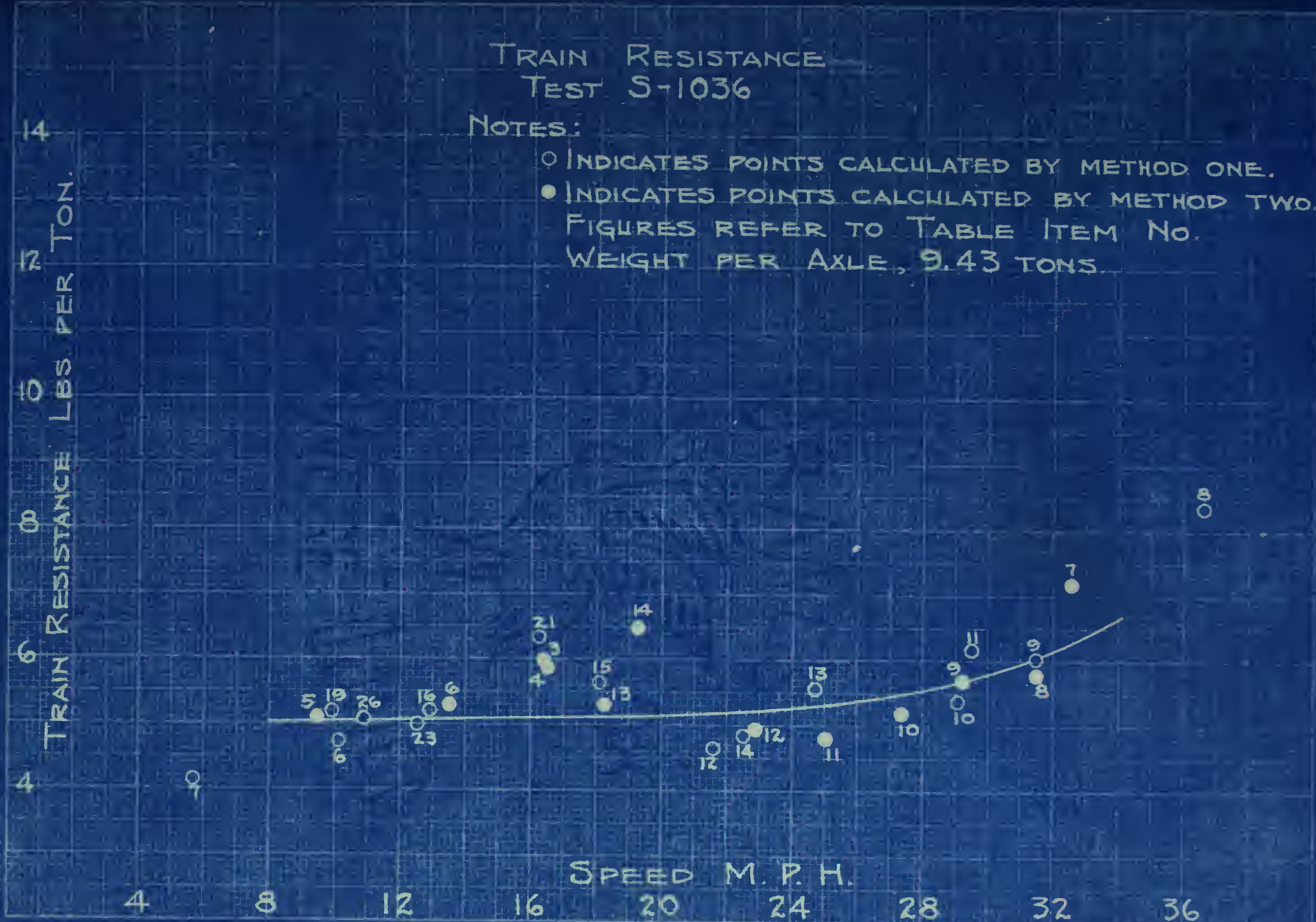
# T E S T  N O. S - 1036

## METHOD TWO - TRAIN RESISTANCE OVER A SECTION

### CENTER OF MASS 966 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. V1 | Speed at Exit M.P.H. V2 | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 3 | 118.27-117.73 | 2888 | 11850 | 16.41 | 16.41 | 16.41 | +0.18 | 0 | $-52^{\circ}$ R | 4 | 5.98 |
| 4 | 117.73-117.18 | 2904 | 11750 | 16.50 | 16.50 | 16.50 | +0.36 | 0 | $-52^{\circ}$ R | 4 | 5.86 |
| 5 | 111.20-110.68 | 2768 | 23900 | 9.44 | 9.44 | 9.44 | +18.70 | 0 | $-12^{\circ}$ R | 4 | 5.09 |
| 6 | 101.46-101.01 | 2372 | 17350 | 14.45 | 12.82 | 13.48 | +12.91 | 0 | $-75^{\circ}$ R | 4.5 | 5.26 |
| 7 | 96.30-95.71 | 3100 | 4600 | 30.40 | 34.50 | 32.50 | -28.45 | 0 | $+81^{\circ}$ R | 8 | 7.19 |
| 8 | 94.14-93.40 | 3924 | 3300 | 30.95 | 31.25 | 31.48 | -11.70 | 0 | $+75^{\circ}$ R | 7 | 5.78 |
| 9 | 90.51-90.02 | 2572 | 5850 | 28.80 | 29.50 | 29.25 | -9.96 | 0 | $+68^{\circ}$ R | 6 | 5.64 |
| 10 | 89.18-88.72 | 2412 | 6200 | 27.75 | 26.95 | 27.42 | -1.97 | 0 | $+63^{\circ}$ R | 5 | 5.18 |
| 11 | 83.72-82.99 | 3856 | 7250 | 24.50 | 25.75 | 25.03 | -5.89 | 0 | $+26^{\circ}$ R | 6 | 4.80 |
| 12 | 81.19-81.64 | 2348 | 6200 | 22.86 | 22.86 | 22.86 | -4.72 | 0 | $+35^{\circ}$ R | 4 | 4.95 |
| 13 | 104.61-103.13 | 3884 | 14700 | 21.53 | 14.85 | 18.25 | +17.00 | 0 | $+64^{\circ}$ R | 5 | 5.30 |
| 14 | 109.85-109.10 | 3972 | 11600 | 15.17 | 23.90 | 19.30 | -17.22 | 0 | $+68^{\circ}$ R | 1 | 6.47 |

* See page 35, Appendix A.


TRAIN RESISTANCE
TEST S-1036
NOTES:
○ INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE, 9.43 TONS.
TRAIN RESISTANCE LBS PER TON.
SPEED M.P.H.
4
6
8
10
12
14
4
8
12
16
20
24
28
32
36

TEST NO. S - 1038

From Champaign to Gilman - October 15, 1908.

Freight train No. Extra 573 - North. Engine No. 573.

500 Pound Spring. 1 square inch Piston Area.

Total weight behind measuring draw-bar, 2144 tons, including No.17.

Train length, 1650 ft. Number of Cars, 41. Empties 3 Loads 38

Weight per axle, 13.07 tons.

Kind of Cars: 32 Coal 7 Box 1 Caboose 1 Test.

Weather: Fine. Temperature 58° F., at start, 72° F., at end of test.

## T E S T  N O. S - 1038

### METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location: Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration: Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 5 | 117.32 | 9800 | 0 | +0.96 | 0 | +16°L | 16 | 24.00 | 4.21 |
| 6 | 115.84 | 10400 | 0 | +2.08 | 0 | +13°L | 16 | 23.15 | 4.06 |
| 7 | 113.84 | 14350 | 0 | +8.01 | 0 | +13°L | 13 | 16.90 | 3.65 |
| 9 | 106.00 | 5500 | 0 | -13.60 | 0 | +19°L | 19 | 38.60 | 7.72 |
| 10 | 100.53 | 13200 | 0 | +2.85 | 0 | +14°L | 15 | 20.75 | 5.07 |
| 11 | 99.29 | 8150 | 0 | +5.18 | 0 | +20°L | 19 | 33.30 | 5.76 |
| 12 | 93.18 | 8300 | 0 | -0.96 | 0 | +7°L | 18 | 28.40 | 4.24 |
| 14 | 89.55 | 10200 | 0 | +1.44 | 0 | +21°L | 17 | 24.00 | 4.21 |
| 15 | 88.74 | 10100 | 0 | -1.85 | 0 | +21°L | 17 | 24.60 | 5.41 |
| 16 | 87.71 | 9000 | 0 | +2.78 | 0 | +16°L | 19 | 27.50 | 3.14 |
| 17 | 87.04 | 8450 | 0 | +1.28 | 0 | +6°L | 20 | 28.50 | 3.45 |
| 18 | 86.42 | 10750 | 0 | +0.64 | 0 | +10°L | 16 | 24.80 | 4.77 |
| 19 | 97.86 | 6800 | +0.0984 | -28.15 | 0 | +19°L | 17 | 35.92 | 4.60 |
| 21 | 97.54 | 3350 | +0.0699 | -24.95 | 0 | +17°L | 19 | 38.35 | 4.46 |
| 22 | 97.76 | 6200 | +0.0880 | -28.15 | 0 | +18°L | 18 | 36.90 | 5.29 |
| 23 | 98.90 | 9050 | -0.0802 | +16.30 | 0 | +25°L | 16 | 29.95 | 5.57 |
| 24 | 103.05 | 22800 | -0.0370 | +29.10 | 0 | +7°L | 9 | 12.85 | 3.09 |
| 25 | 105.90 | 5500 | 0 | -8.42 | 0 | +20°L | 18 | 37.55 | 5.76 |

* See page 35. Appendix A.

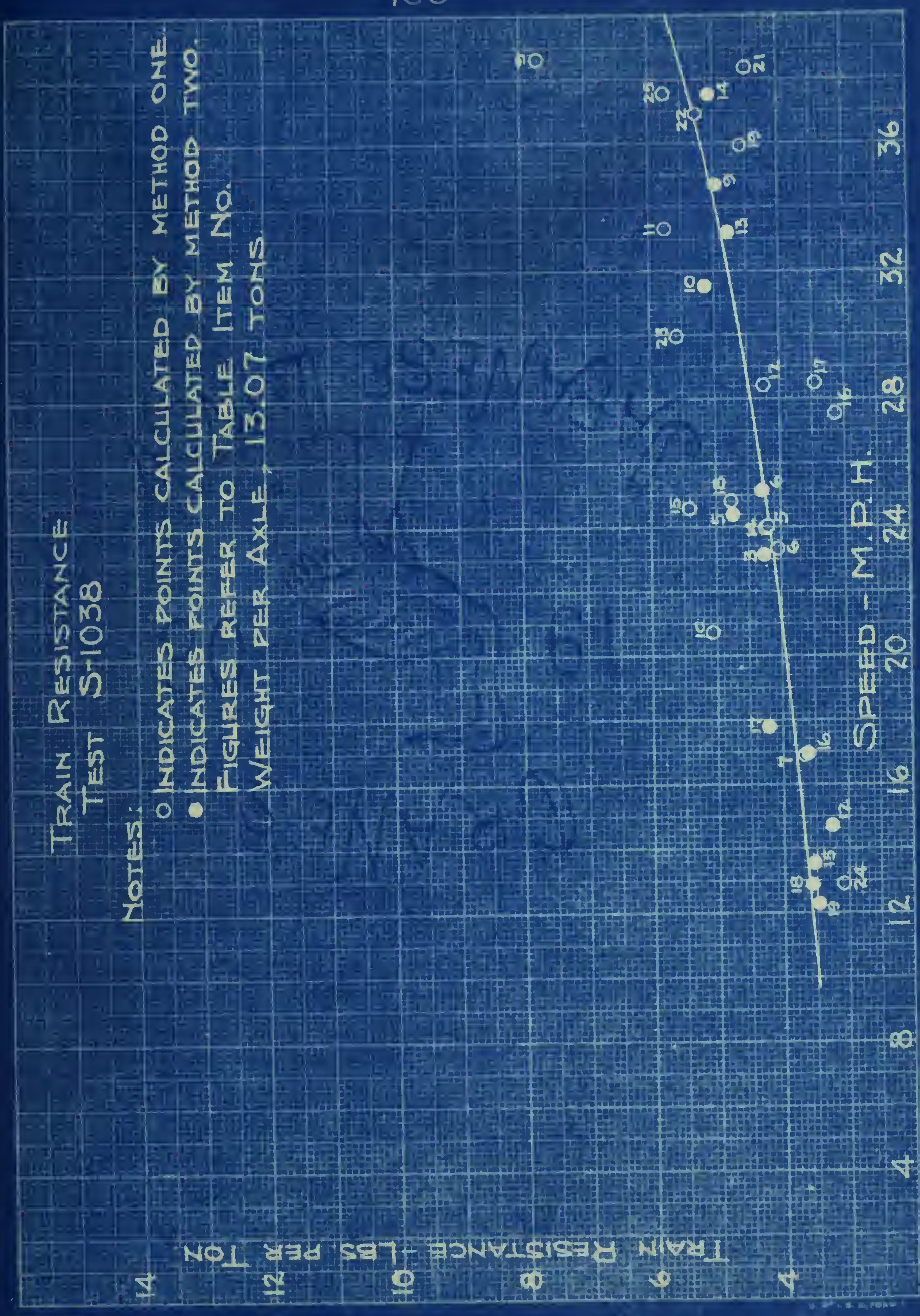
TEST NO. S - 1038

METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS 825 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. V1 | Speed at Exit M.P.H. V2 | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up - Down | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 3 | 117.06-118.18 | 5935 | 10000 | 23.65 | 24.15 | 23.12 | +0.43 | 0 | +16° L | 16 | 4.23 |
| 5 | 88.77-89.55 | 4260 | 10250 | 24.20 | 24.75 | 24.20 | -0.95 | 0 | -21° L | 17 | 4.71 |
| 6 | 85.84-86.36 | 2768 | 10250 | 25.10 | 25.90 | 25.15 | -1.33 | 0 | -10° L | 16 | 4.28 |
| 9 | 98.24-97.76 | 2544 | 7100 | 31.95 | 36.90 | 34.69 | -28.65 | 0 | +21° L | 16 | 4.97 |
| 10 | 99.29-98.90 | 2080 | 8100 | 32.80 | 29.95 | 31.51 | +11.92 | 0 | +22° L | 17 | 5.14 |
| 12 | 103.44-103.05 | 2050 | 19200 | 18.75 | 12.85 | 14.70 | +31.70 | 0 | +5° L | 11 | 3.22 |
| 13 | 105.18-104.58 | 3168 | 6850 | 35.10 | 30.60 | 33.20 | +12.66 | 0 | +15° L | 17 | 4.78 |
| 14 | 106.26-105.48 | 4120 | 6050 | 36.40 | 36.40 | 37.50 | -5.92 | 0 | +20° L | 18 | 5.06 |
| 15 | 111.10-110.65 | 2384 | 20150 | 14.75 | 13.55 | 13.53 | +18.04 | 0 | -21° L | 11 | 3.54 |
| 16 | 110.24-109.82 | 2236 | 17050 | 15.00 | 19.75 | 16.94 | -1.89 | 0 | +16° L | 14 | 3.61 |
| 17 | 114.74-114.24 | 2608 | 13750 | 18.70 | 17.80 | 17.80 | +8.10 | 0 | +13° L | 13 | 4.22 |
| 18 | 111.10-110.24 | 4536 | 20650 | 14.30 | 14.30 | 12.85 | +15.95 | 0 | | | 3.59 |
| 19 | 110.65-110.25 | 2152 | 21400 | 12.80 | 14.30 | 12.22 | +13.73 | 0 | | | 3.48 |

* See page 35, Appendix A.



TRAIN RESISTANCE
TEST S-1038
NOTES.
O INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE, 13.07 TONS.
TRAIN RESISTANCE - LBS PER TON
SPEED - M.P.H.
4
8
12
16
20
24
28
32
36
6
10
14

TEST NO. S - 1040

From Champaign to Gilman - October 24, 1908

Freight train No. Extra 567 - North. Engine No. 567.

500 Pound Spring. 1 square inch Piston Area.

Total weight behind measuring draw-bar, 2152 tons, including No.17.

Train length, 1830 ft. Number of Cars, 47. Empties 2 Loads 45.

Weight per axle, 11.44 tons.

Kind of Cars: 21 Box 22 Coal 1 Gondola 1 Test 1 Caboose.

Weather: Drizzly, rainy at intervals. Temperature 58° F., at start, 52° F., at end of test.

## T E S T  N O. S - 1040

### METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location: Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 6 | 114.68 | 16500 | 0 | +7.72 | 0 | +40° R | 8 | 10.77 | 4.75 |
| 10 | 102.99 | 28400 | 0 | +27.10 | 0 | +21° R | 8 | 3.82 | 2.92 |
| 12 | 100.64 | 15100 | 0 | +7.22 | 0 | +33° R | 10 | 12.45 | 4.28 |
| 15 | 88.71 | 8900 | 0 | -1.53 | 0 | +17° R | 13 | 28.20 | 4.71 |
| 16 | 86.32 | 9850 | 0 | -0.26 | 0 | +14° R | 11 | 24.82 | 4.67 |
| 20 | 101.55 | 8900 | -0.0441 | +9.53 | 0 | +34° R | 13 | 18.72 | 4.66 |
| 24 | 103.48 | 23000 | -0.0511 | +30.00 | 0 | +41° R | 10 | 11.40 | 4.13 |
| 25 | 108.45 | 13200 | -0.0255 | +9.81 | 0 | +36° R | 11 | 17.05 | 4.82 |

* See page 35, Appendix A.

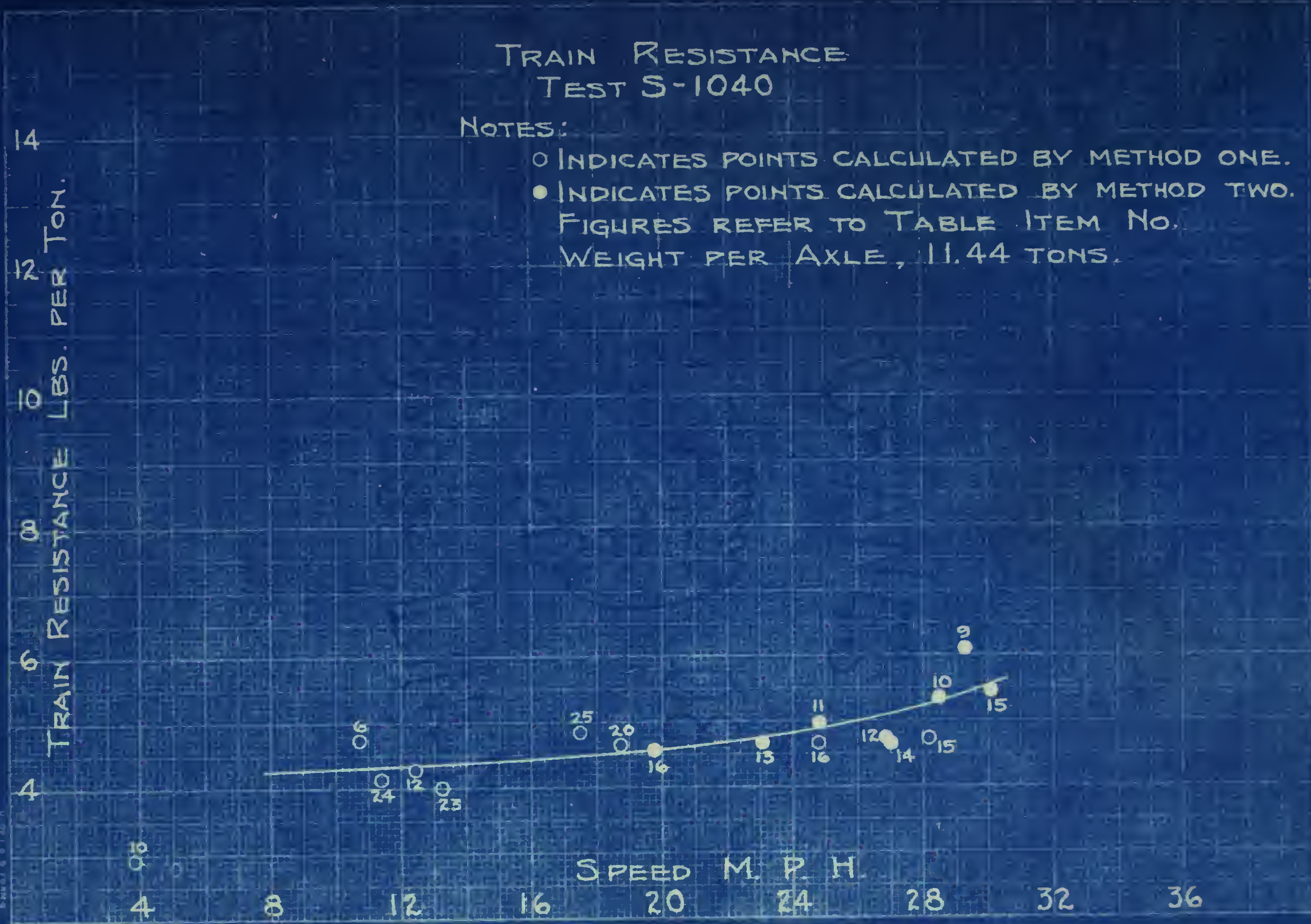
## T E S T  N O. S - 1040

### METHOD TWO - TRAIN RESISTANCE OVER A SECTION

CENTER OF MASS 900 FT. FROM HEAD OF TRAIN

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20* | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. V1 | Speed at Exit M.P.H. V2 | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 9 | 90.52-90.03 | 2584 | 8500 | 28.70 | 29.62 | 29.36 | -9.61 | 0 | +23°R | 13 | 6.14 |
| 10 | 89.29-88.52 | 3768 | 8750 | 28.80 | 28.20 | 28.54 | -1.64 | 0 | +17°R | 13 | 5.33 |
| 11 | 86.32-95.91 | 2180 | 10150 | 24.62 | 24.62 | 24.77 | -0.70 | 0 | +14°R | 11 | 4.98 |
| 12 | 83.83-83.16 | 3548 | 7000 | 26.40 | 27.10 | 26.88 | -4.99 | 0 | +15°R | 12 | 4.74 |
| 13 | 93.64-93.20 | 2200 | 4000 | 22.37 | 21.74 | 23.10 | -5.04 | 0 | +26°R | 12 | 4.64 |
| 14 | 83.83-83.00 | 4360 | 7250 | 26.70 | 27.80 | 27.00 | -5.82 | 0 | +15°R | 12 | 4.64 |
| 15 | 106.10-105.70 | 1988 | 7450 | 29.20 | 29.85 | 30.10 | -8.76 | 0 | +27°R | 13 | 5.45 |
| 16 | 103.87-104.64 | 4056 | 15100 | 22.75 | 16.70 | 19.75 | +17.20 | 0 | +20°R | 9 | 4.56 |

* See page 35, Appendix A.


TRAIN RESISTANCE
TEST S-1040
NOTES:
○ INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM No.
WEIGHT PER AXLE, 11.44 TONS.
TRAIN RESISTANCE LBS. PER TON.
14
12
10
8
6
4
SPEED M. P. H.
4
8
12
16
20
24
28
32
36

TEST NO. S - 1043

From Champaign to Mattoon - November 7, 1908.

Freight train No. Extra 706 - South. Engine No. 706.

500 Pound Spring. 1 square inch Piston Area.

Total weight behind measuring draw-bar, 1118 tons, excluding No.17.

Train length, 2580 ft. Number of Cars 66, Empties 65 Loads 1.

Weight per axle, 4.12 tons.

Kind of Cars: 15 Box 49 Coal 1 Tank 1 Caboose.

Weather: Fine. Temperature 38° F., at start, 53° F., at end of test.

T E S T  N O. S - 1043

METHOD ONE - TRAIN RESISTANCE AT A POINT

| 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item No. | Location: Mile Post Number | Total Draw-bar Pull Pounds P | Acceleration: Miles per Hour per Second A | Grade Ft. per Mile + Up - Down G | Curvature | Wind Direction | Wind Velocity M.P.H. | Speed of Train M.P.H. | Net Train Resistance Lbs. per Ton R |
| 1 | 142.05 | 11300 | 0 | -0.14 | 0 | $+23^{\circ}$L | 8. | 24.35 | 10.15 |
| 2 | 143.25 | 9400 | +0.0124 | -8.80 | 0 | $+20^{\circ}$L | 11. | 26.70 | 10.51 |
| 3 | 150.77 | 11000 | +0.0165 | +2.00 | 0 | $+24^{\circ}$L | 7. | 19.50 | 7.43 |
| 4 | 156.10 | 13300 | 0 | +9.21 | 0 | $+22^{\circ}$L | 6. | 15.80 | 8.41 |
| 5 | 157.78 | 11700 | 0 | +2.97 | 0 | $+ 6^{\circ}$L | 7 | 17.75 | 9.33 |
| 6 | 168.23 | 15100 | 0 | +14.13 | 0 | $+64^{\circ}$L | 4 | 12.55 | 8.14 |
| 7 | 168.78 | 17000 | +0.0106 | +14.21 | 0 | $+56^{\circ}$L | 4 | 11.80 | 8.76 |
| 8 | 147.29 | 7400 | 0 | -12.11 | 0 | $+15^{\circ}$L | 13 | 32.30 | 11.21 |
| 9 | 143.90 | 8650 | 0 | -7.96 | 0 | $+11^{\circ}$L | 11 | 27.75 | 10.75 |

* See page 35, Appendix A.

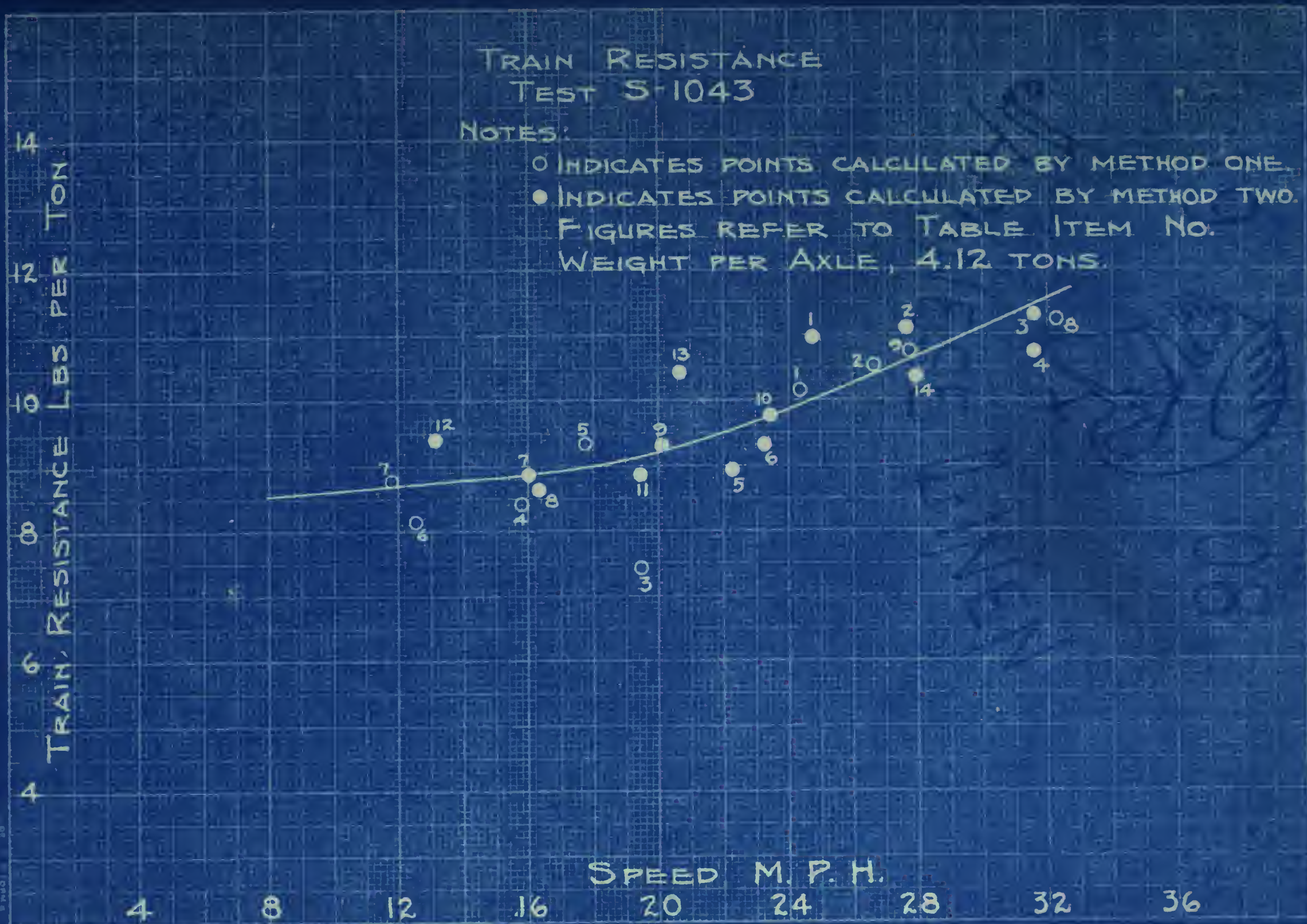
TEST NO. 1043

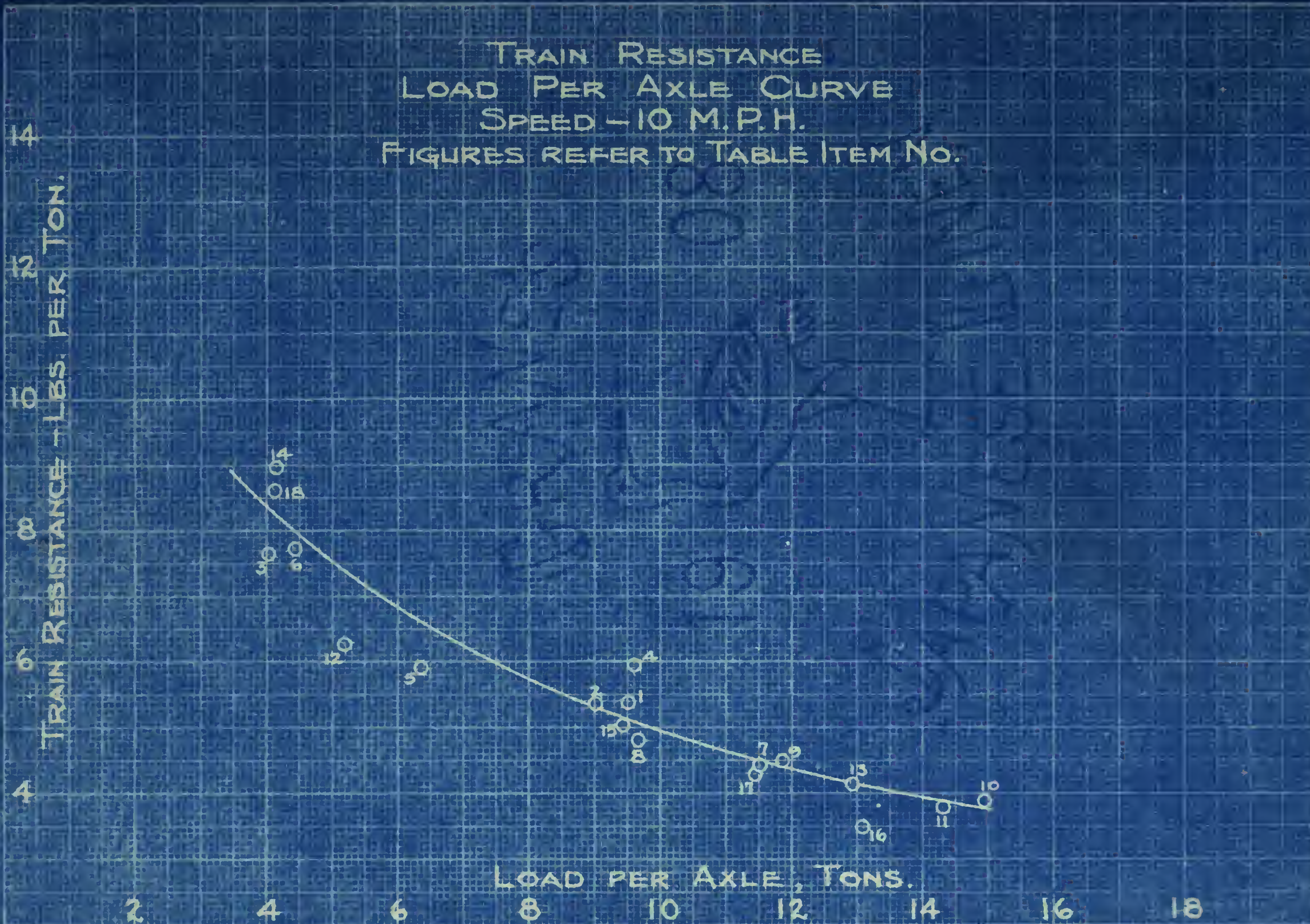
METHOD TWO - TRAIN RESISTANCE OVER A SECTION

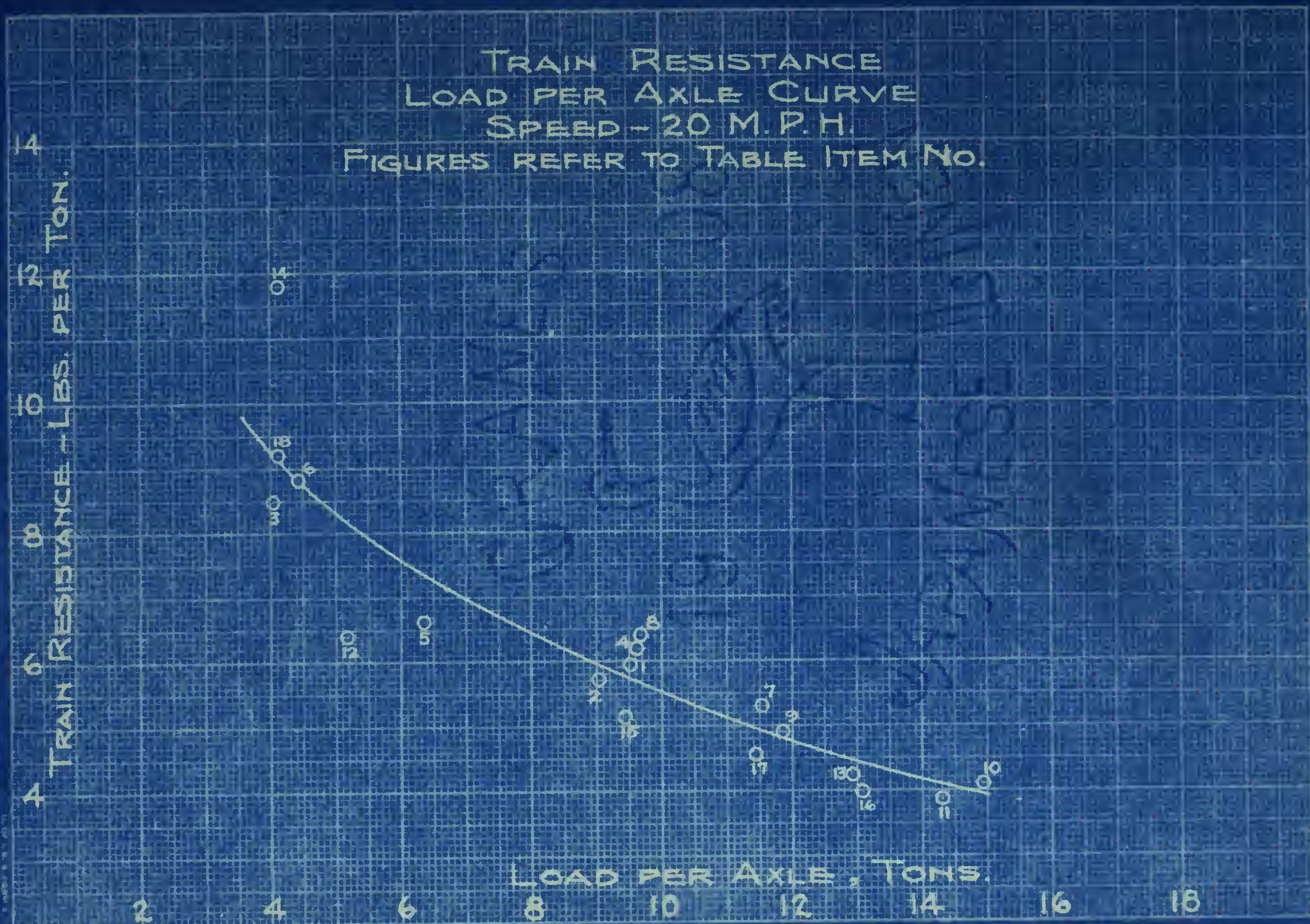
CENTER OF MASS 1300 FT. FROM HEAD OF TRAIN

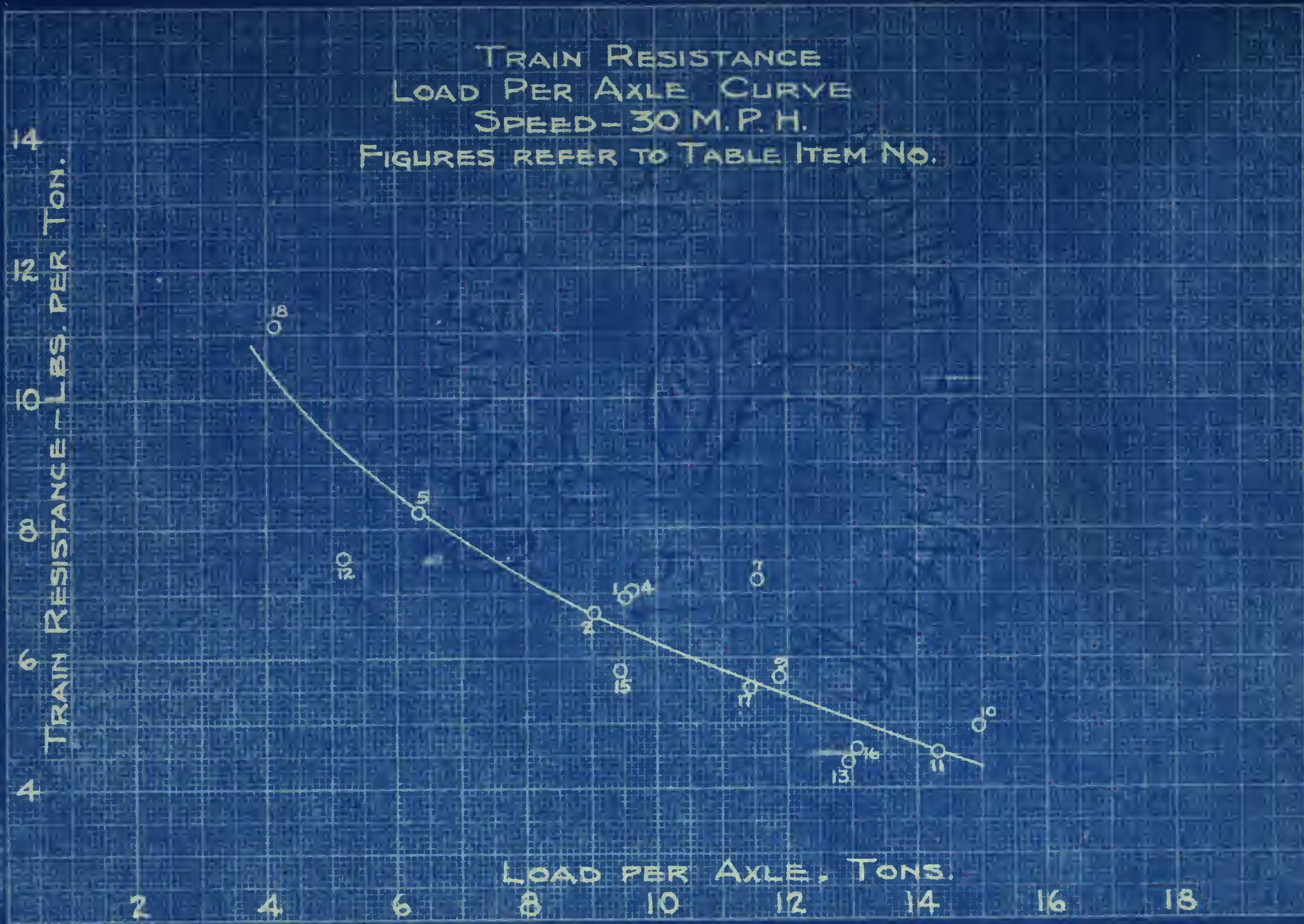
| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Limits of Section from M.P. to M.P. | Length of Section Ft S | Total Mean Draw-bar Pull Lbs. P | Speed at Entrance M.P.H. V1 | Speed at Exit M.P.H. V2 | Avg. Speed M.P.H. V | Grade Ft. per Mile + Up - Down G | Curvature | Avg. Wind Direction | Avg. Wind Velocity M.P.H. | Net Avg. Train Resistance Lbs. per Ton R |
| 1 | 139.25-140.49 | 6540 | 10500 | 24.70 | 25.50 | 24.76 | -3.97 | 0 | +29°L | 8 | 10.97 |
| 2 | 143.70-144.40 | 3652 | 8800 | 27.96 | 26.87 | 27.67 | -5.12 | 0 | +14°L | 11 | 11.01 |
| 3 | 146.20-147.52 | 6960 | 7500 | 29.43 | 32.10 | 31.60 | -16.61 | 0 | +6°L | 13 | 11.29 |
| 4 | 147.52-148.31 | 4172 | 7600 | 32.10 | 30.42 | 31.60 | -5.50 | 0 | +7°L | 13 | 10.72 |
| 5 | 151.00-152.47 | 7832 | 11100 | 20.00 | 22.50 | 22.25 | -0.03 | 0 | +15°L | 9 | 8.93 |
| 6 | 152.47-153.45 | 5112 | 9450 | 22.50 | 23.90 | 23.24 | -4.70 | 0 | +25°L | 10 | 9.31 |
| 7 | 155.27-156.20 | 4952 | 13350 | 16.33 | 15.75 | 16.07 | +9.02 | 0 | +22°L | 6 | 8.79 |
| 8 | 156.20-157.16 | 5028 | 13850 | 15.75 | 17.00 | 16.32 | +8.34 | 0 | +22°L | 6 | 8.63 |
| 9 | 159.65-166.66 | 5316 | 10620 | 18.60 | 22.75 | 20.13 | -5.94 | 0 | -14°L | 8 | 9.41 |
| 10 | 166.66-162.22 | 8248 | 8500 | 22.75 | 20.90 | 23.43 | -3.84 | 0 | +15°L | 8 | 9.76 |
| 11 | 165.74-166.74 | 5276 | 11600 | 20.25 | 18.02 | 19.45 | +7.04 | 0 | -52°L | 7 | 8.88 |
| 12 | 168.43-169.53 | 5292 | 15400 | 12.40 | 16.27 | 13.16 | +8.20 | 0 | +56°L | 4 | 9.40 |
| 13 | 169.53-170.72 | 6272 | 11400 | 16.27 | 22.15 | 20.70 | -7.87 | 0 | -17°L | 9 | 10.41 |
| 14 | 145.58-146.20 | 3276 | 9150 | 26.90 | 29.40 | 27.94 | -13.96 | 0 | +5°L | 11 | 10.35 |

* See page 35, Appendix A.


TRAIN RESISTANCE
TEST S-1043
NOTES.
O INDICATES POINTS CALCULATED BY METHOD ONE.
● INDICATES POINTS CALCULATED BY METHOD TWO.
FIGURES REFER TO TABLE ITEM NO.
WEIGHT PER AXLE, 4.12 TONS.
TRAIN RESISTANCE LBS PER TON
SPEED M.P.H.
4
6
8
10
12
14
4
8
12
16
20
24
28
32
36


TRAIN RESISTANCE
LOAD PER AXLE CURVE
SPEED – 10 M.P.H.
FIGURES REFER TO TABLE ITEM NO.
TRAIN RESISTANCE – LBS. PER TON.
LOAD PER AXLE, TONS.
14
12
10
8
6
4
2
4
6
8
10
12
14
16
18
14
18
3
6
12
5
2
1
4
15
8
7
9
17
13
16
11
10


Train Resistance
Load per Axle Curve
Speed - 20 M.P.H.
Figures refer to Table Item No.
Train Resistance - Lbs. per Ton.
Load per Axle, Tons.
4
6
8
10
12
14
2
4
6
8
10
12
14
16
18


TRAIN RESISTANCE
LOAD PER AXLE CURVE
SPEED - 30 M.P.H.
FIGURES REFER TO TABLE ITEM NO.
TRAIN RESISTANCE - LBS. PER TON.
LOAD PER AXLE, TONS.
14
12
10
8
6
4
2
4
6
8
10
12
14
16
18
18
5
12
1
4
2
7
15
9
17
10
16
13
11

# TABLE
## TO ACCOMPANY
# SUMMARY OF TRAIN RESISTANCE CURVES
## UNIVERSITY OF ILLINOIS

| CURVE NO. | TEST NO. | TOTAL TONNAGE | NO. CARS | NO. LOADS | NO. EMPTIES | LOAD PER AXLE TONS |
|---|---|---|---|---|---|---|
| 1 | S-1013 | 2549 | 67 | 57 | 10 | 9.51 |
| 2 | S-1015 | 2489 | 69 | 61 | 8 | 9.02 |
| 3 | S-1016 | 1161 | 72 | 0 | 72 | 4.03 |
| 4 | S-1017 | 2532 | 66 | 53 | 13 | 9.61 |
| 5 | S-1018 | 1353 | 49 | 15 | 33 | 6.35 |
| 6 | S-1019 | 1572 | 89 | 14 | 75 | 4.43 |
| 7 | S-1021 | 2809 | 62 | 51 | 11 | 11.52 |
| 8 | S-1023 | 2243 | 58 | 41 | 17 | 9.68 |
| 9 | S-1027 | 2185 | 46 | 43 | 3 | 11.86 |
| 10 | S-1030A | 2035 | 34 | 32 | 2 | 14.95 |
| 11 | S-1030B | 2341 | 41 | 38 | 3 | 14.30 |
| 12 | S-1031 | 747 | 36 | 6 | 30 | 5.18 |
| 13 | S-1033 | 2275 | 44 | 42 | 2 | 12.93 |
| 14 | S-1034 | 1259 | 76 | 0 | 76 | 4.14 |
| 15 | S-1036 | 1961 | 52 | 44 | 8 | 9.43 |
| 16 | S-1038 | 2144 | 41 | 38 | 3 | 13.07 |
| 17 | S-1040 | 2152 | 47 | 45 | 2 | 11.44 |
| 18 | S-1043 | 1118 | 66 | 1 | 65 | 4.12 |

APPENDIX C.

APPARATUS

A DESCRIPTION OF DYNAMOMETER CAR NO. 17

Dynamometer Car No. 17, belonging jointly to the University of Illinois and the Illinois Central Railroad Company was used in all tests. It is designed for general experimental work on steam roads, and is especially adapted for the determination of train resistance and for use in making locomotive road tests. It was first built and equipped in 1900, but in 1907 was dismantled and rebuilt, the old recording apparatus being discarded and replaced by new equipment which is here described. An outside view of the car is shown in Figure 1 and inside views in Figures 2 and 3. It was originally built particularly heavy in order to withstand the usage it receives in freight service, and when rebuilt the center sills were reinforced by continuous steel channels and steel platforms were added. It is 45 feet 4 inches long and 40 feet over the end sills, 8 feet 4 3/8 inches wide inside, 9 feet 1 5/8 inches outside, with an extreme width of 10 1/2 feet over the observation windows. The height from the rail to the roof is 12 feet and from the rail to the top of the cupola 14 feet 10 inches. About 15 feet in the rear end is occupied by the berths, lockers, closets and toilet room, leaving 25 feet working space, in which the recording apparatus, work benches, etc., are placed. The car is lighted by electricity, being supplied with an axle light equipment, made by the Bliss Electric Car Lighting Company.


Figure 1

DYNAMOMETER CAR No. 17

Figure 2

INTERIOR VIEW

Figure 7
INTERIOR VIEW

Views of the recording apparatus are shown in Figures 4, 5 and 6. It provides means for obtaining a continuous graphical record of the following data:-

Curve of draw-bar pull.

Speed curve.

Record of work performed by locomotive at tender draw-bar.

Record of time.

Record of position of mile posts, stations, etc.

Record of throttle opening.

Record of reverse lever position.

Record of locomotive boiler pressure.

Record of air brake applications.

Record of wind direction.

Record of wind velocity.

Besides the above, any data which proves of interest in special tests, such as time of taking indicator cards, etc., may be recorded upon the chart by means of additional pens provided for such purposes.

All of the above data are recorded in the form of curves or lines with offsets on a continuous strip of paper 36 inches wide, which travels across the top of the recording table. This paper can be driven either at a constant speed, by means of a motor, current for which is supplied by the

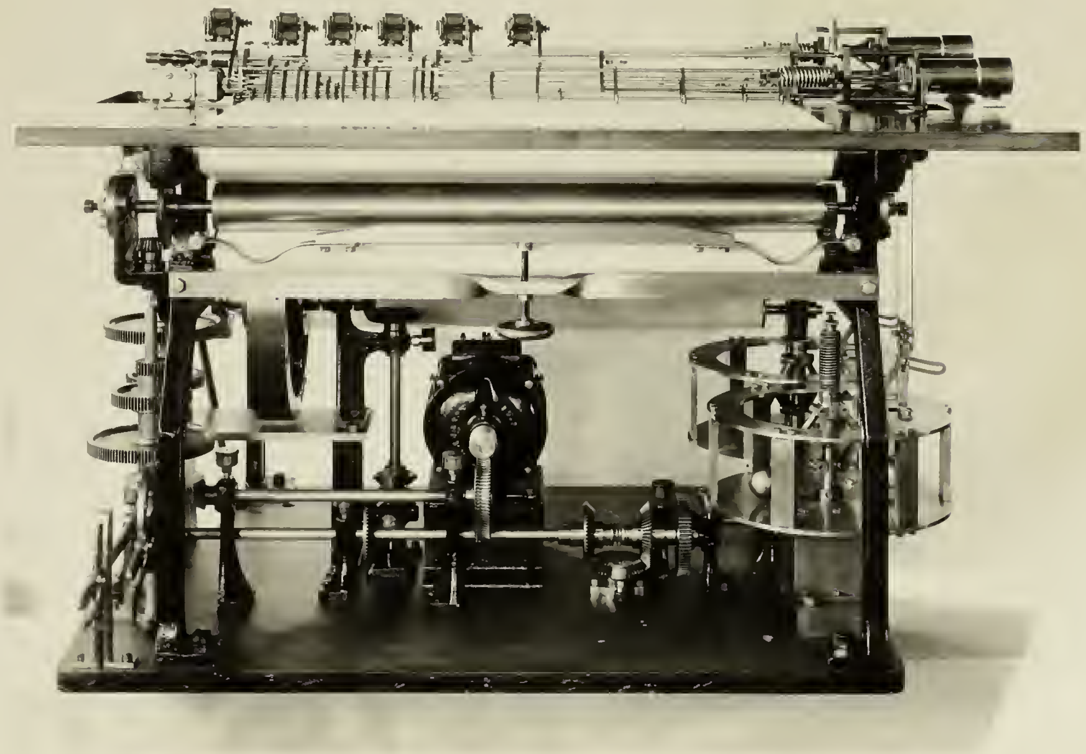


Figure 4

RECORDING APPARATUS

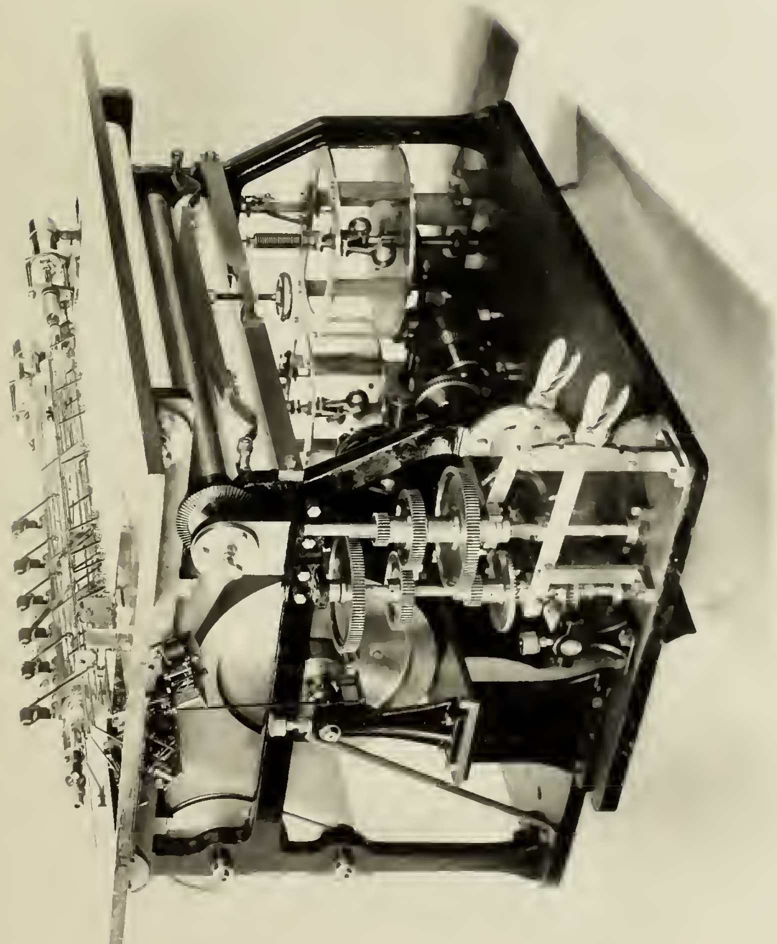


Figure 5

RECORDING APPARATUS

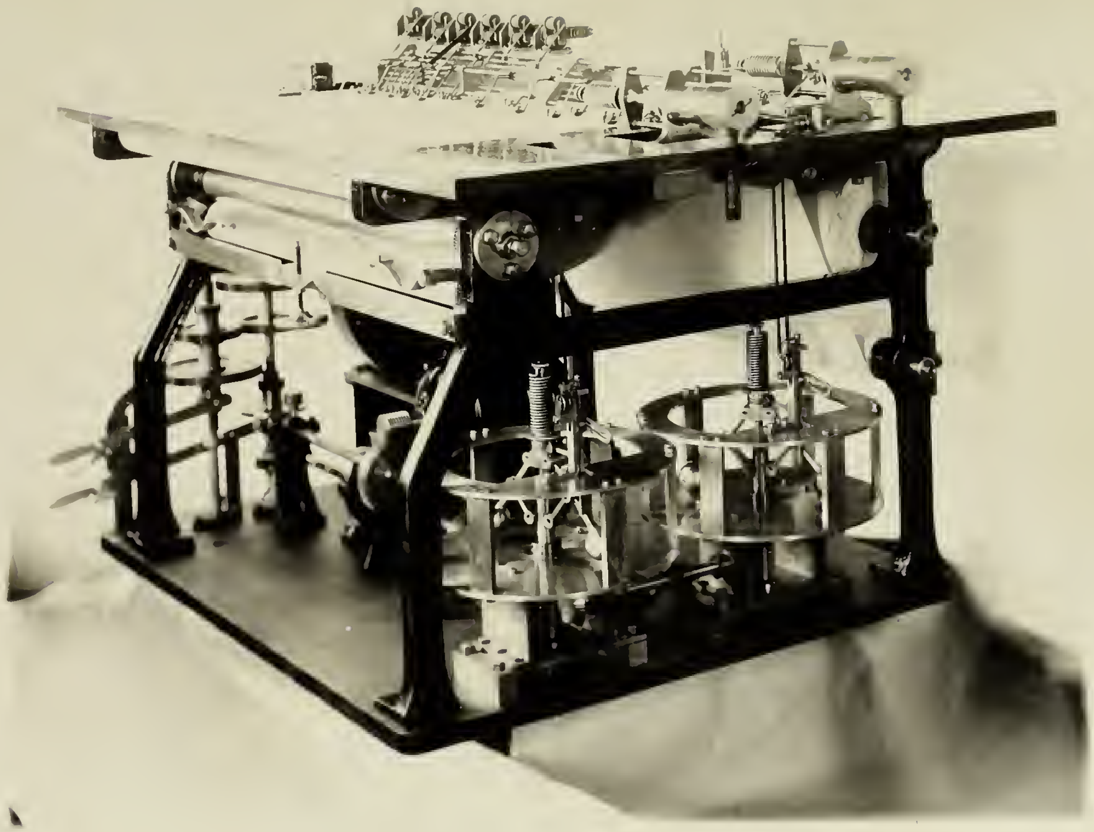


Figure [illegible]

RECORDING APPARATUS

storage battery, which forms a part of the axle light equipment; or at a speed proportional to the speed of the car. In the first case, the records are obtained on a time base, in the second, upon a distance base. In the latter case, the paper is driven from the axle of an auxiliary two-wheeled truck, which can be seen in Figure 1. This truck is so constructed that its wheels can be lifted from the rails from within the car. They are never run except during a test. A sectional view showing the transmission gear from this truck is shown in Figure 7. It may be seen from the figure that a vertical shaft, extending up into the car, is driven from the truck axle by means of two pairs of bevel gears, which are carried in a cast iron gear case, and run in oil. This vertical shaft is provided with two universal joints and a slip joint, which permit relative motion between the truck wheels and car body. At its upper end it carries a bevel gear, which meshes with two other bevel gears carried on a horizontal shaft, which may be seen near the bottom in Figure 4. These two bevels are so attached by means of a ratchet device to the horizontal shaft, that it is driven in the same direction for both directions of car travel. This horizontal shaft so drives the paper (thru a clutch and a set of change speed gears) that the paper travel is in the same direction at all times. The lower lever, shown at the left in Figure 5, operates the cluth, by means of which the paper may be driven either from the motor or from the center truck

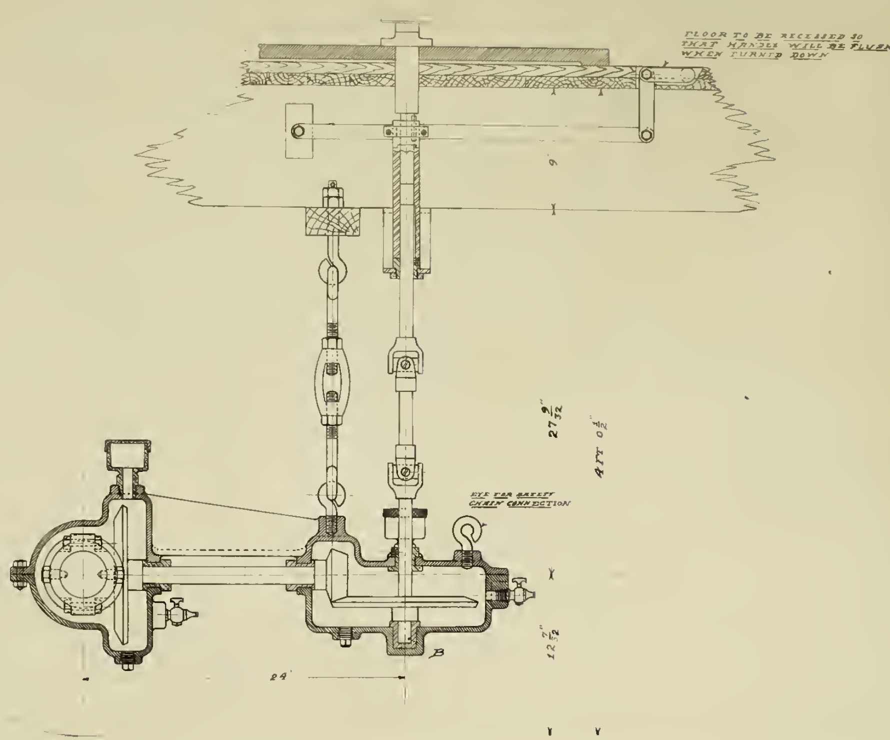



Figure 7

TRANSMISSION GEAR FROM AUXILIARY TRUCK AXLE

axle, or it may be thrown out of connection with both of these. The upper lever controls the change speed gears, by means of which the paper may be driven at a constant speed of 3 3/4, 15 or 60 inches per minute, or at a rate of 1/16, 1/4 or 1 inch per 100 feet of car travel.

The recording apparatus as a whole is entirely self contained, and is mounted on a heavy cast iron base plate. As mounted in the car, it is enclosed in a glass case to protect the instruments from dust and grit. All of the active recording pens are arranged to move in a straight line, at right angles to the direction of paper travel. They are all carried on hollow aluminum rods, lightness being thus secured, which diminishes disturbances due to inertia and friction. The datum or zero pens are arranged in a straight line 1 1/2 inches ahead of the line in which the active pens move.

DESCRIPTIVE OF THE METHODS OF OBTAINING THE DIFFERENT RECORDS.

DRAW-BAR PULL

What is commonly known as an oil or hydraulic transmission dynamometer is used to measure the draw-bar pull. A heavy cast iron cylinder with an inside diameter of 10 inches, is fastened to the underframing of the car near the front end in line with the draw-bar. The pull upon the draw-bar is taken against oil contained in this cylinder. The pressure upon the oil, caused by the draw-bar pull, is transmitted

to the recording indicator, which forms a part of the recording apparatus. Figure 8 shows a sectional view of the cylinder, and also the system of oil piping. Since the working pressure in the oil is rather high, (a little over 1,000 pounds per square inch for a draw-bar pull of 80,000 pounds), it is necessary to take every precaution against leakage. Both the piston and cylinder bore are ground, since any form of piston packing is inadmissable on account of its friction.

In order to avoid the difficulties attending the use of a stuffing box around the piston rod, the particular form of cylinder construction shown was adopted. The cylinder casting is built solid in front, the piston rod extending towards the back from the piston. The pull on the draw-bar is delivered to the piston as a thrust from behind by means of the yoke connection shown in Figure 8. With this construction, the leakage has proven to be small and easily taken care of. The only result of leakage is that the piston is allowed to travel slowly forward in the cylinder. By means of an electric "telltale" device, an alarm bell is automatically rung before the piston reaches the end of its travel. Fresh oil is then forced into the cylinder by means of a pump provided for that purpose. This may be done during the progress of a test without invalidating the draw-bar pull record. Even in heavy freight work, when the draw-bar pull is great and the speed slow, it is seldom necessary to thus replace oil in the cylinder oftener than every 25 or 30 miles. The

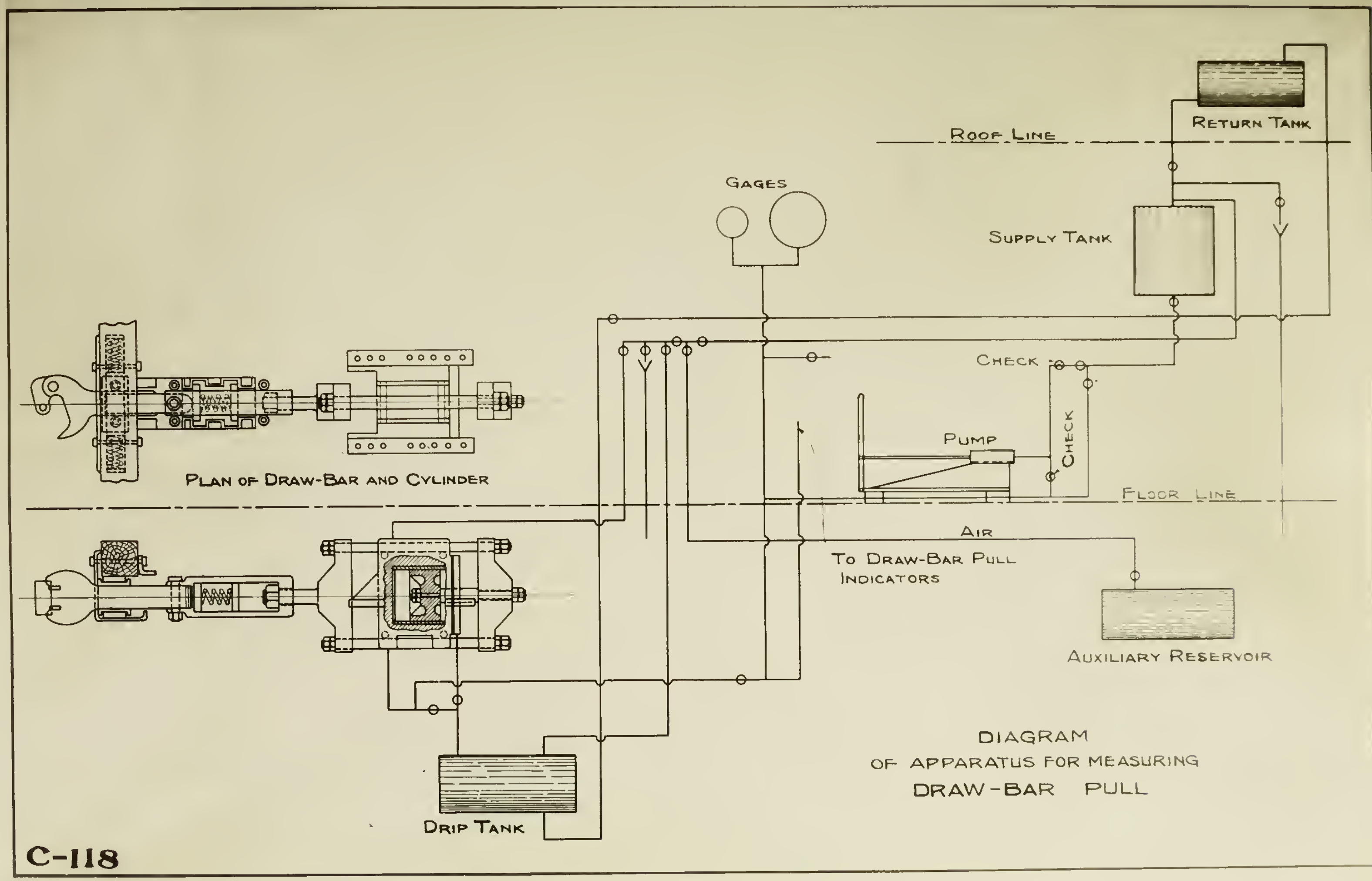

Return Tank
Roof Line
Gages
Supply Tank
Check
Pump
Check
Floor Line
Air
To Draw-Bar Pull
Indicators
Auxiliary Reservoir
Plan of Draw-Bar and Cylinder
Drip Tank
DIAGRAM
OF APPARATUS FOR MEASURING
DRAW-BAR PULL
C-118

Figure 8

oil which leaks by the piston drains into the drip tank shown in Figure 8, and from there is forced back through the return tank and into the supply tank by air pressure.

In order to lessen friction due to side pulls on curves, the draw-bar is connected to the draw-bar yoke by means of a pin about which it can swivel. Besides this, both the draw-bar and yoke are guided between rollers. This construction is shown in Figure 8.

The draw-bar pull recording indicators, which are provided in duplicate, may be seen on top of the table, at the right, in Figures 4, 5 and 6. They were built by the Crosby Steam Gage and Valve Company and are similar in design to the outside spring Crosby steam engine indicator, but much larger. One special feature in their design is that three different pistons, having areas of 1/2, 1 and 1 1/2 square inches respectively, may be used in them, a different bushing, with a bore to fit the piston being used in each case. By changing these pistons and using different springs, it is possible to make use of the total six inches of available pen travel in all classes of work, from the lightest passenger trains to the heaviest freight trains.

SPEED RECORD

Two types of speed recorder are used, one for high and the other for low speeds. The high speed recorders, which are provided in duplicate, are of the centrifugal type

and are used for speeds above 15 miles per hour. In their construction knife edges were used where possible, in order to reduce friction to a minimum. They are also designed so that they are not affected by jolts and vibrations of the car. It was desired to have the movement of the speed pen proportional to the changes in speed, or in other words to have equal changes in speed represented by the same pen movement throughout the total range. In order to accomplish this, it was found necessary to use a cam with a properly shaped profile. For low speeds a Boyer speed recorder (geared up so that it runs much faster than usual), is used. Its upper limit is about 35 miles per hour.

RECORD OF WORK DONE BY THE LOCOMOTIVE

When the paper is driven at a rate which is proportional to the car travel, the area under the curve drawn by the draw-bar pull pen is a measure of the work done by the locomotive at the tender draw-bar, assuming that the measuring draw-bar of the test car is attached to the tender draw-bar. This area is measured and recorded by a specially designed planimeter, which rests on the chart and is attached directly to the draw-bar pull pen rod. Its record is made by a pen controlled by an electro-magnet, the circuit through this electro magnet being closed by the planimeter at the completion of each 5 square inches of area under the draw-bar pull curve.

TIME RECORD

The time record is made by a pen which is moved by a cam controlled by an electro-magnet. The circuit through this electro-magnet is closed every 5 seconds by a special clock. The cam is so constructed that the pen is drawn about 1/16 of an inch to one side every 5 seconds for one minute, when it is returned the total distance it has traveled during the minute, and starts over again. It thus draws a line which shows both 5 second and 1 minute intervals. For convenience in working up the chart, two time records, one at each edge, are provided.

OTHER RECORDS

The wind direction and velocity records are made by a wind vane and anemometer, which may be seen above the car roof in Figure 1. They give the direction and velocity of the wind relative to the car. Since the speed and direction of motion of the car are known, the absolute direction and velocity of the wind may be obtained. It is possible that the air disturbances set up around the sides and roof of the car render untrustworthy the records from these time instruments. Sufficient experience has not thus far been obtained to warrant conclusions concerning the accuracy of their records.

The record of air brake applications is made by a

standard steam engine indicator to which pressure from the brake cylinder is piped. It thus gives a record showing the number of applications, their duration and intensity.

The mile post pen, which is controlled by an electro-magnet, draws a continuous line, and at mile posts, stations, etc., is drawn slightly aside by the magnet which is operated by an observer in the observation window.

Records of the locomotive boiler pressure, throttle opening, reverse lever position, etc., are also made by pens which are controlled by electro-magnets. Wires are run to the locomotive cab, and observers there make the contacts which operate the magnets. Special codes are used in making these records.

Figure 9 shows a sample section of an actual record made by the recording apparatus. A profile of the road, drawn subsequent to the making of the chart, has been added below, since it is of assistance in interpreting some of the other records. No discussion of the chart seems necessary, since the significance of the various lines is indicated upon the record itself. The chart as reproduced is exactly as drawn during the progress of a test, except that some of the lettering has been added to explain the meaning of the record, and the profile has been added as explained above. The mile post numbers, indicator card numbers (if indicator cards are being taken) time, etc., are of course, stamped upon the chart during the progress of the test.

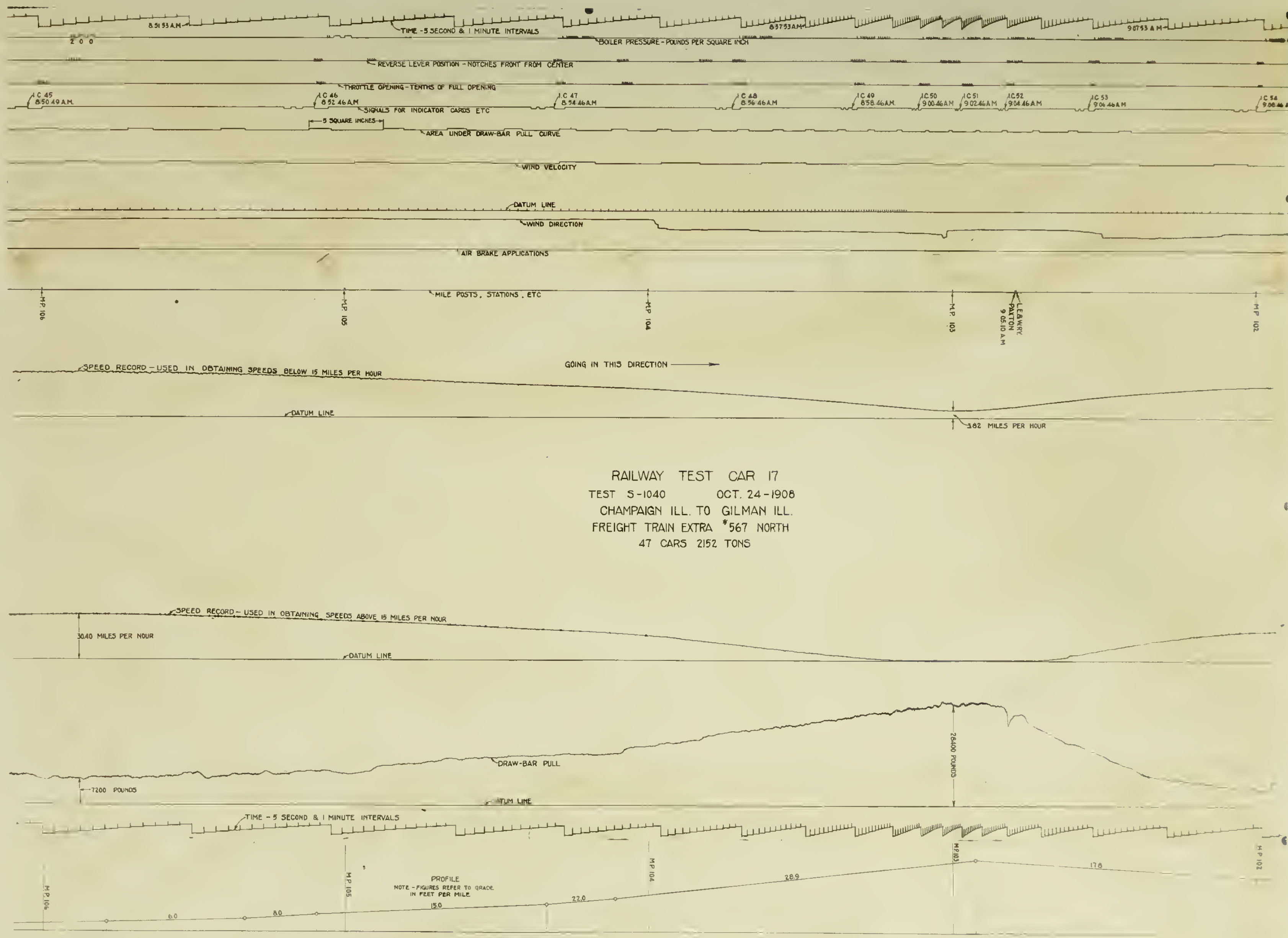



Figure 9

SAMPLE DYNAMOMETER RECORD